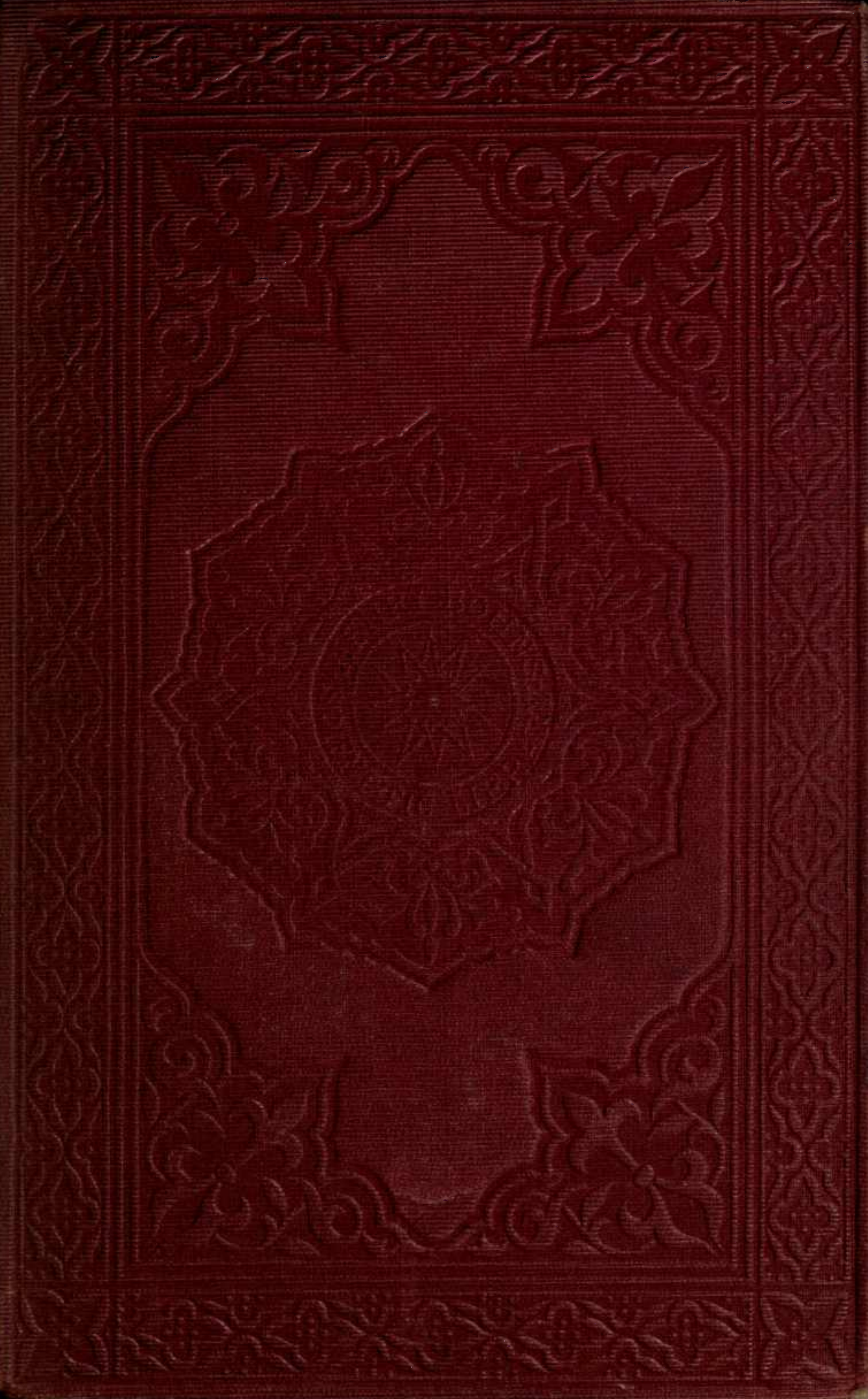

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Naturæ vero rerum vis atque majestas in omnibus momentis fide caret, si quis modo partes
ejus ac non totam complectatur animo.—Plin., *Hist. Nat.* lib. vii. c. 1.

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VOL. III.

LONDON:
BELL & DALDY, YORK STREET, COVENT GARDEN.
1871.

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1871
V. 3

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS,
STAMFORD STREET AND CHARING CROSS.

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# SPECIAL RESULTS OF OBSERVATION

IN THE

# DOMAIN OF COSMICAL PHENOMENA.

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## INTRODUCTION.

In accordance with the object I have proposed to myself, and which, as far as my own powers and the present state of science permit, I have regarded as not unattainable, I have, in the preceding volumes of Cosmos, considered Nature in a twofold point of view. In the first place, I have endeavoured to present her in the pure objectiveness of external phenomena; and, secondly, as the reflection of the image impressed by the senses upon the inner man, that is, upon his ideas and feelings.

The external world of phenomena has been delineated under the scientific form of a general picture of nature in her two great spheres, the uranological and the telluric or terrestrial. This delineation begins with the stars, which glimmer amidst nebulæ in the remotest realms of space, and passing from our planetary system to the vegetable covering of the earth, descends to the minutest organisms which float in the atmosphere, and are invisible to the naked eye. In order to give due prominence to the consideration of the existence of one common bond encircling the whole organic world, of the control of eternal laws, and of the causal connexion, as far as yet known to us, of whole groups of phenomena, it was necessary to avoid the accumulation of isolated facts. This precaution seemed especially requisite where, in addition to the dynamic action of moving forces, the powerful influence of a specific difference of matter manifests itself in the terrestrial portion of the universe. The problems presented to us in the sidereal, or uranological, sphere of the Cosmos, are, considering their nature, in as far as they admit of being observed, of extraordinary simplicity, and capable, by means of the attractive force of matter and the quantity of its mass, of being submitted to exact calculation in accordance with the theory of motion. If, as I believe, we are justified in regarding the revolving meteor-asteroids (aërolites) as portions of our planetary system, their fall upon the earth constitutes the sole means by which we are brought in contact with cosmical substances of a recognisable heterogeneity.[1] I here refer to the cause which has hitherto rendered terrestrial phenomena less amenable to the rules of mathematical deduction than those mutually disturbing and re-adjusting movements of the cosmical bodies, in which the fundamental force of homogeneous matter is alone manifested.

I have endeavoured, in my delineation of the earth, to arrange natural phenomena in such a manner as to indicate their causal connexion. In describing our terrestrial sphere, I have considered its form, mean density, electro-magnetic currents, the processes of polar light, and the gradations according to which heat increases with the increase of depth. The reaction of the planet's interior on its outer crust implies the existence of volcanic activity; of more or less contracted circles of waves of commotion (earthquake waves), and their effects, which are not always purely dynamic; and of the eruptions of gas, of mud, and of thermal springs. The upheaval of fire-erupting mountains must be regarded as the highest demonstration of the inner terrestrial forces. We have therefore depicted volcanoes, both central and chain formations, as generative no less than as destructive agents, and as constantly forming before our eyes for the most part periodic rocks (rocks of eruption); we have likewise shown in contrast with this formation how sedimentary rocks are in the course of precipitation from fluids, which hold their minutest particles in solution or suspension. Such a comparison of matter still in the act of development and solidification with that already consolidated in the form of strata of the earth's crust, leads us to the distinction of geognostic epochs, and to a more certain determination of the chronological succession of those formations in which lie entombed extinct genera of animals and plants—the fauna and flora of a former world, whose ages are revealed by the order in which they occur. The origin, transformation, and upheaval of terrestrial strata, exert, at certain epochs, an alternating action on all the special characteristics of the physical configuration of the earth's surface; influencing the distribution of fluids and solids, and the extension and articulation of continental masses in a horizontal and vertical direction. On these relations depend the thermal conditions of oceanic currents, the meteorological processes in the aërial investment of our planet, and the typical and geographical distribution of organic forms. Such a reference to the arrangement of telluric phenomena presented in the picture of nature, will, I think, suffice to show that the juxtaposition of great, and apparently complicated, results of observation, facilitates our insight into their causal connection. Our impressions of nature will, however, be essentially weakened, if the picture fail in warmth of colour by the too great accumulation of minor details.

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[1] *Cosmos*, vol. i. pp. 45–47, 125.

In a carefully-sketched representation of the phenomena of the material world, completeness in the enumeration of individual features has not been deemed essential, neither does it seem desirable in the delineation of the reflex of external nature on the inner man. Here it was necessary to observe even stricter limits. The boundless domain of the world of thought, enriched for thousands of years by the vigorous force of intellectual activity, exhibits, among different races of men, and in different stages of civilization, sometimes a joyous, sometimes a melancholy tone of mind;[2] sometimes a delicate appreciation of the beautiful, sometimes an apathetic insensibility. The mind of man is first led to adore the forces of nature and certain objects of the material world; at a later period it yields to religious impulses of a higher and purely spiritual character.[3] The inner reflex of the outer world exerts the most varied influence on the mysterious process of the formation of language,[4] in which the original corporeal tendencies, as well as the impressions of surrounding nature, act as powerful concurring elements. Man elaborates within himself the materials presented to him by the senses, and the products of this spiritual labour belong as essentially to the domain of the Cosmos as do the phenomena of the external world.

As a reflected image of Nature, influenced by the creations of excited imagination, cannot retain its truthful purity, there has arisen besides the actual and external world, an ideal and internal world, full of fantastic, and partly symbolical myths, heightened by the introduction of fabulous animal forms, whose several parts are derived from the organisms of the present world, and sometimes even from the relics of extinct species.[5] Marvellous flowers and trees spring from this mythic soil, as the giant ash of the Edda-Songs, the world-tree, Yggdrasil, whose branches tower above the heavens, while one of its triple roots penetrates to the "foaming cauldron springs" of the lower world.[6] Thus the cloud-region of physical myths is filled with pleasing or with fearful forms, according to the diversity of character in nations and climates; and these forms are preserved for centuries in the intellectual domain of successive generations.

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[2] *Cosmos*, vol. i. pp. 3–5; vol. ii. pp. 376 and 456.

[3] *Ibid.*, vol. ii. pp. 392–396, and 411–415.

[4] *Ibid.*, vol. i. pp. 366–369; vol. ii. pp. 473–473.

[5] M. von Olfer's *Ueberreste vorweltlicher Riesenthiere in Beziehung auf Ostasiatische Sagen* in the *Abh. der Berl. Akad.*, 1832, s. 51. On the opinion advanced by Empedocles regarding the cause of the extinction of the earliest animal forms, see Hegel's *Geschichte der Philosophie*, bd. ii. s. 344.

If the present work does not fully bear out its title, the adoption of which I have myself designated as bold and inconsiderate, the charge of incompleteness applies especially to that portion of the COSMOS which treats of spiritual life; that is, the image reflected by external nature on the inner world of thought and feeling. In this portion of my work I have contented myself with dwelling more especially upon those objects which lie in the direction of long-cherished studies; on the manifestation of a more or less lively appreciation of nature in classical antiquity and in modern times; on the fragments of poetical descriptions of nature, the colouring of which has been so essentially influenced by individuality of national character, and the religious monotheistic view of creation; on the fascinating charm of landscape-painting; and on the history of the contemplation of the physical universe, that is, the history of the recognition of the universe as a whole, and of the unity of phenomena,—a recognition gradually developed during the course of two thousand years.

In a work of so comprehensive a character, the object of which is to give a scientific, and at the same time an animated description of nature, a first imperfect attempt must rather lay claim to the merit of inciting than to that of satisfying inquiry. *A Book of Nature*, worthy of its exalted title, can never be accomplished until the physical sciences, notwithstanding their inherent imperfectibility, shall, by their gradual development and extension, have attained a higher degree of advancement, and until we shall have gained a more extended knowledge of the two grand divisions of the Cosmos,—the external world, as made perceptible to us by the senses; and the inner, reflected intellectual world.

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[6] See, for the world-tree Yggdrasil, and the rushing (foaming) cauldron-spring Hvergelmir, the *Deutsche Mythologie* of Jacob Grimm, 1844, s. 530, 756; also Mallet's *Northern Antiquities*, (Bohn's edition), 1847, pp. 410, 489, and 492 and frontispiece to ditto

I think I have here sufficiently indicated the reasons which determined me not to give greater extension to the general picture of nature. It remains for this third and last volume of my *Cosmos*, to supply much that is wanting in the previous portions of the work, and to present those results of observation on which the present condition of scientific opinion is especially grounded. I shall here follow a similar mode of arrangement to that previously adopted, for the reasons which I have advanced, in the delineation of nature. But before entering upon the individual facts on which special departments of science are based, I would fain offer a few more general explanatory observations. The unexpected indulgence with which my undertaking has been received by a large portion of the public, both at home and abroad, renders it doubly imperative that I should once more define, as distinctly as possible, the fundamental ideas on which the whole work is based, and say something in regard to those demands which I have not even attempted to satisfy, because, according to my view of empirical—*i. e.*, experimental—science, they did not admit of being satisfied. These explanatory observations involuntarily associate themselves with historical recollections of the earlier attempts made to discover the one universal idea to which all phenomena, in their causal connection, might be reduced, as to a sole principle.

The fundamental principle[7] of my work on the Cosmos, as enunciated by me more than twenty years ago, in the French and German lectures I gave at Paris and Berlin, comprehended the endeavour to combine all cosmical phenomena in one sole picture of nature; to show in what manner the common conditions, that is to say, the great laws, by which individual groups of these phenomena are governed, have been recognized; and what course has been pursued in ascending from these laws to the discovery of their causal connexion. Such an attempt to comprehend the plan of the universe—the order of nature—must begin with a generalization of particular facts, and a knowledge of the conditions under which physical changes regularly and periodically manifest themselves; and must conduct to the thoughtful consideration of the results yielded by empirical observation, but not to "a contemplation of the universe based on speculative deductions and development of thought alone, or to a theory of absolute unity independent of experience." We are, I here repeat, far distant from the period when it was thought possible to concentrate all sensuous perceptions into the unity of one sole idea of nature. The true path was indicated upwards of a century before Lord Bacon's time, by Leonardo da Vinci, in these few words: "Cominciare dall' esperienza e per mezzo di questa scoprirne la ragione."[8]—"Commence by experience, and by means of this discover the reason." In many groups of phenomena we must still content ourselves with the recognition of empirical laws; but the highest and more rarely attained aim of all natural inquiry must ever be the discovery of their *causal connexion*.[9] The most satisfactory and distinct evidence will always appear where the laws of phenomena admit of being referred to mathematical principles of explanation. Physical cosmography constitutes merely in some of its parts a cosmology. The two expressions cannot yet be regarded as identical. The great and solemn spirit that pervades the intellectual labour, of which the limits are here defined, arises from the sublime consciousness of striving towards the infinite, and of grasping all that is revealed to us amid the boundless and inexhaustible fulness of creation, development, and being.

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[7] *Cosmos*, vol. i. pp. 28–31, and 51–60.

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[8] *Op. cit.* vol. ii. p. 661.

[9] In the Introductory Observations, in *Cosmos*, v. i. p. 30, it should not have been generally stated that "the ultimate object of the experimental sciences is to discover laws, and to trace their progressive generalization." The clause "in many kinds of phenomena," should have been added. The caution with which I have expressed myself in the 2nd

This active striving which has existed in all ages, must frequently and under various forms, have deluded men into the idea, that they had reached the goal, and discovered the principle which could explain all that is variable in the organic

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vol. of this work (p. 694), on the relation borne by Newton to Kepler, cannot, I think, leave a doubt that I clearly distinguish between the discovery and interpretation of natural laws, *i. e.*, the explanation of phenomena. I there said of Kepler: "The rich abundance of accurate observations furnished by Tycho Brahe, the zealous opponent of the Copernican system, laid the foundation for the discovery of those eternal laws of the planetary movements which prepared imperishable renown for the name of Kepler, and which, interpreted by Newton, and proved to be *theoretically* and *necessarily* true, have been transferred into the bright and glorious domain of thought, as *the intellectual recognition of nature.*" Of Newton, I said (p. 736): "We close it [the great epoch of Galileo, Kepler, Newton, and Leibnitz,] with the figure of the earth as it was then recognized from *theoretical* conclusions. Newton was enabled to give an explanation of the system of the universe, because he succeeded in discovering the force from whose action the laws of Kepler necessarily result." Compare on this subject ("On Laws and Causes") the admirable remarks in Sir John Herschel's address at the fifteenth meeting of the British Association at Cambridge, 1845, p. xlii.; and *Edinb. Rev.* vol. 87, 1848, pp. 180–183.

world, and all the phenomena revealed to us by sensuous perception. After men had for a long time, in accordance with the earliest ideas of the Hellenic people, venerated the agency of spirits, embodied in human forms,[10] in the creative, changing, and destructive processes of nature; the germ of a scientific contemplation developed itself in the physiological fancies of the Ionic school. The first principle of the origin of things, the first principle of all phenomena, was referred to two causes[11]—either to concrete material principles, the so-called *elements* of Nature, or to processes of rarefaction and condensation, sometimes in accordance with mechanical, sometimes with dynamic views. The hypothesis of four or five materially differing elements, which was probably of Indian origin, has continued from the æra of the didactic poem of Empedocles, down to the most recent times, to imbue all opinions on natural philosophy—a primeval evidence and monument of the tendency of the human mind to seek a generalization and simplification of ideas, not only with reference to the forces, but also to the qualitative nature of matter.

In the latter period of the development of the Ionic physiology, Anaxagoras of Clazomenæ advanced from the postulate of simply dynamic forces of matter, to the idea of a spirit independent of all matter, uniting and distributing the homogeneous particles of which matter is composed. The world-arranging Intelligence (νοῦς) controls the *continuously progressing* formation of the world, and is the primary source of all motion, and therefore of all physical phenomena. Anaxagoras explains the apparent movement of the heavenly bodies from east to west by the assumption of a centrifugal force,[12] on the intermission of which, as we have already observed, the fall of meteoric stones ensues. This hypothesis indicates the origin of those theories of rotatory motion which more than two thousand years afterwards attained considerable cosmical importance from the labours of Descartes, Huygens, and Hooke. It would be foreign to the present work, to discuss whether the world-arranging Intelligence of the philosopher of Clazomenæ indicates[13] the godhead itself, or the mere pantheistic notion of a spiritual principle animating all nature.

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[10] In the memorable passage (*Metăph.* xii. 8. p. 1074, Bekker.) in which Aristotle speaks of "the relics of an earlier acquired and subsequently lost wisdom," he refers with extraordinary freedom and significance to the veneration of physical forces, and of gods in human forms: "much," says he, "has been mythically added for the *persuasion of the multitude*, as also on account of the laws and for other useful ends."

[11] The important difference in these philosophical directions *τρόποι*, is clearly indicated in Arist. *Phys. Auscult.* 1. 4, p. 187, Bekk. (Compare Brandis in the *Rhein. Museum für Philologie*, Jahrg. iii. s. 105.)

In striking contrast with these two divisions of the Ionic school, is the mathematical symbolism of the Pythagoreans, which in like manner embraced the whole universe. Here, in the world of physical phenomena cognizable by the senses, the attention is solely directed to that which is normal in configuration (the five elementary forms), to the ideas of numbers, measure, harmony, and contrarieties. Things are reflected in numbers which are, as it were, an imitative representation (μίμησις) of them. The boundless capacity for repetition, and the illimitability of numbers, is typical of the character of eternity and of the infinitude of nature. The essence of things may be recognized in the form of numerical relations: their alterations and metamorphoses as numerical combinations. Plato, in his Physics, attempted to refer the nature of all substances in the universe, and their different stages of metamorphosis, to corporeal forms, and these again to the simplest triangular plane figures.[14] But in reference to ultimate principles (the elements, as it were, of the elements), Plato exclaims, with modest diffidence, "God alone, and those whom he loves among men, know what they are." Such a mathematical mode of treating physical phenomena, together with the development of the atomic theory, and the philosophy of measure and harmony, have long obstructed the development of the physical sciences, and misled fanciful inquirers into devious tracks, as is shown in the history of the physical contemplation of the universe. "There dwells a captivating charm, celebrated by all antiquity, in the simple relations of time and space, as manifested in tones, numbers, and lines."[15]

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[12] *Cosmos*, vol. i. pp. 122, 123, (note), and vol. ii. p. 690 (and note). Simplicius, in a remarkable passage, p. 491, most distinctly contrasts the centripetal with the centrifugal force. He there says, "the heavenly bodies do not fall in consequence of the centrifugal force being superior to the inherent falling force of bodies and to their downward tendency." Hence, Plutarch in his work, *De facie in orbe Lunæ*, p. 923, compares the moon, in consequence of its not falling to the earth, to "a stone in a sling." For the actual signification of the περιχώρησις of Anaxagoras, compare Schaubach in *Anaxag. Clazom. Fragm.* 1827, pp. 107–109.

[13] Schaubach, *Op. cit.* pp. 151–156, and 185–189. Plants are likewise said to be animated by the intelligence, νοῦς; tot. *de Plant.* i. p. 815, Bekk.

The idea of the harmonious government of the universe reveals itself in a distinct and exalted tone throughout the writings of Aristotle. All the phenomena of nature are depicted in the *Physical Lectures* (*Auscultationes Physicæ*) as moving, vital agents of one general cosmical force. Heaven and nature, (the telluric sphere of phenomena,) depend upon the "unmoved motus of the universe."[16] The "ordainer" and the ultimate cause of all sensuous changes must be regarded as something non-sensuous and distinct from all matter.[17] Unity in the different expressions of material force is raised to the rank of a main principle, and these expressions of force are themselves always reduced to motions. Thus we find already in "the book of the soul"[18] the germ of the undulatory theory of light. The sensation of sight is occasioned by a vibration—a movement of the medium between the eye and the object seen—and not by emissions from the object or the eye. Hearing is compared with sight, as sound is likewise a consequence of the vibration of the air.

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[14] Compare on this portion of Plato's mathematical physics, Böckh *De platonico syst. cælestium globorum*, 1810 et 1811; Martin, *Etudes sur le Timée*, tom. ii. pp. 234–242; and Brandis in the *Geschichte der Griechisch-Römischen Philosophie*, Th. ii. Abth. i. 1844, § 375.

[15] *Cosmos*, vol. ii. p. 736, note; compare also Gruppe *Ueber die Fragmente des Archytas*, 1840, s. 33.

Aristotle, while he teaches men to investigate generalities in the particulars of perceptible unities, by the force of reflective reason, always includes the whole of nature, and the internal connexion not only of forces, but also of organic forms. In his book on the parts (organs) of animals, he clearly intimates his belief that throughout all animate beings there is a scale of gradation, in which they ascend from lower to higher forms. Nature advances in an uninterrupted progressive course of development, from the inanimate or "elementary" to plants and animals; and "lastly, to that which, though not actually an animal, is yet so nearly allied to one, that on the whole there is little difference between them."[19] In the transition of formations, "the gradations are almost imperceptible."[20] The unity of nature was to the Stagirite the great problem of the Cosmos. "In this unity," he observes, with singular animation of expression, "there is nothing unconnected or out of place, as in a bad tragedy."[21]

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[16] Aristot. *Polit.* vii. 4, p. 1326, and *Metaph.* xii. 7, p. 1072, 10 Bekk. and xii. 10, p. 1074–5. The pseudo-Aristotelian work *de Mundo*, which Osann ascribed to Chrysippus (see *Cosmos*, vol. ii. p. 380) also contains (cap. 6, p. 397) a very eloquent passage on the *world-orderer* and *world-sustainer*.

[17] The proofs are collected in Ritter, *History of Philosophy* (Bohn, 1838-46), Vol. 3, p. 180 *et seq*.

[18] Compare Aristot. *de Anima*, ii. 7 pag. 419. In this passage the analogy with sound is most distinctly expressed; although in other portions of his writings Aristotle has greatly modified his theory of vision. Thus in *de Insomniis*, cap. 2, p. 459, Bekker., we find the following words :—" It is evident that sight is no less an active than a passive agent, and that vision not only experiences some action from the air (the medium), but itself also acts upon the medium." He adduces in evidence of the truth of this proposition, that a new and very pure metallic mirror will, under certain conditions, when looked at by a woman, retain on its surface cloudy specks that cannot be removed without difficulty. Compare also Martin, *Etudes sur le Timée de Platon.* tom. ii. pp. 159–163.

The endeavour to reduce all the phenomena of the universe to one principle of explanation, is manifest throughout the physical works of this profound philosopher and accurate observer of nature; but the imperfect condition of science, and ignorance of the mode of conducting experiments, *i.e.*, of calling forth phenomena under definite conditions, prevented the comprehension of the causal connection of even small groups of physical processes. All things were reduced to the ever-recurring contrasts of heat and cold, moisture and dryness, primary density and rarefaction—even to an evolution of alterations in the organic world by a species of inner division (antiperistasis) which reminds us of the modern hypothesis of opposite polarities and the contrasts presented by + and —.[22] The so-called solutions of the problems only reproduce the same facts in a disguised form, and the otherwise vigorous and concise style of the Stagirite degenerates in his explanations of meteorological or optical processes, into a self-complacent diffuseness and a somewhat Hellenic verbosity. As Aristotle's inquiries were directed almost exclusively to *motion*, and seldom to differences in matter, we find the fundamental idea, that all telluric natural phenomena are to be ascribed to the impulse of the movement of the heavens—the rotation of the celestial sphere—constantly recurring, fondly cherished and fostered,[23] but never declared with absolute distinctness and certainty.

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[19] Aristot. *de partibus Anim.*, lib. iv. cap. 5, pag. 681, lin. 12. Bekker.

[20] Aristot. *Hist. Anim.*, lib. ix., cap. 1, pag. 588, lin. 10-24. Bekker. When any of the representatives of the four elements in the animal kingdom on our globe fail, as for instance those which represent the element of the purest fire, the intermediate stages may perhaps be found to occur in the moon (Biese, *Die Phil. des Aristoteles;* bd. ii. s. 186). It is singular enough, that the Stagirite should seek in another planet those intermediate links of the chain of organised beings which we find in the extinct animal and vegetable forms of an earlier world.

[21] Aristot. *Metaph.* lib. xiii. cap. 3, pag. 1090, lin. 20, Bekker.

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[22] The *ἀντιπερίστασις* of Aristotle plays an important part in all his explanations of meteorological processes; so also in the works *de generatione et interitu*, lib. ii. cap. 3, p. 330: in the *Meteorologicis*, lib. i. cap. 12, and lib. iii. cap. 3, p. 372, and in the *Problemæ* (lib. xiv. cap. 3, lib. viii, no. 9, p. 888, and lib. xiv. no. 3, p. 909.) which are at all events based on Aristotelian principles. In the ancient polarity hypothesis *κατ ἀντιπερίστασιν* similar conditions attract each other, and dissimilar ones (+ and —) repel each another in opposite directions. (Compare Ideler, *Meteorol. veterum Græc. et Rom.* 1832, p. 10.) The opposite conditions instead of being destroyed by combining together, rather increase the *tension.* The *ψυχρὸν* increases the *θερμόν*; as inversely "in the formation of hail the surrounding heat makes the cold body still colder as the cloud sinks into warmer strata of air." Aristotle explains by his *antiperistatic process* and the polarity of heat, what modern physics have taught us to refer to conduction, radiation, evaporation, and changes in the capacity of heat. See the able observations of Paul Erman in the *Abhandl. der Berliner Akademie auf das* Jahr. 1825, s. 128.

[23] "By the movement of the heavenly sphere, all that is

The impulse to which I refer, indicates only the communication of motion as the cause of all terrestrial phenomena. Pantheistic views are excluded; the Godhead is considered as the highest "ordering unity, manifested in all parts of the universe, defining and determining the nature of all formations, and holding together all things as an absolute power." [24] The main idea and these teleological views are not applied to the subordinate processes of inorganic or elementary nature, but refer specially to the higher organizations [25] of the animal and vegetable world. It is worthy of notice, that in these theories, the Godhead is attended by a number of *astral spirits*, who (as if acquainted with perturbations and the distribution of masses) maintain the planets in their eternal orbits.[26] The stars here

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unstable in natural bodies, and all terrestrial phenomena are produced." Aristot. *Meteor.* i. 2, p. 339, and *de gener. et corrupt.* ii. 10, p. 336.

[24] Aristot. *de Cœlo*, lib. i. c. 9, p. 279, lib. ii. c. 3, p. 286; lib. ii. c. 13, p. 292. Bekker. (Compare Biese, bd. i. s. 352–1, 357.)

[25] Aristot. *Phys. Auscult.* lib. ii. c. 8, p. 199; *de Anima*, lib. iii. c. 12, p. 434; *de Animal. generat.* lib. v. c. 1, p. 778. Bekker.

[26] See the passage in Aristot. *Meteor.* xii. 8, p. 1074, of which there is a remarkable elucidation in the Commentary of Alexander Aphrodisiensis. The stars are not inanimate bodies but must be regarded as active and living beings. (Aristot. *de Cœlo*, lib. ii. cap. 12, p. 292.) They are the most divine of created things; *τὰ θειότερα τῶν φανερῶν*. Aristot. *de Cœlo*, lib. i. cap. 9, p. 278, and lib. ii. cap. 1, p. 284.) In the small pseudo-Aristotelian work, *de Mundo*, which frequently breathes a religious spirit in relation to the preserving almightiness of God, (cap. 6, p. 400,) the high æther is also called divine, (cap. 2, p. 392). That which the imaginative Kepler calls moving spirits (*animæ motrices*) in his work, *Mysterium cosmographicum* (cap. 20, p. 71) is the distorted idea of a force (*virtus*), whose main seat is in the sun (*anima*

reveal the image of the divinity in the visible world. We do not here refer, as its title might lead to suppose, to the little pseudo-Aristotelian work, entitled the "Cosmos," undoubtedly a Stoic production. Although it describes the heavens and the earth, and oceanic and aerial currents, with much truthfulness, and frequently with rhetorical animation and picturesque colouring, it shows no tendency to refer cosmical phenomena to general physical principles based on the properties of matter.

I have purposely dwelt at length on the most brilliant period of the Cosmical views of antiquity, in order to contrast the earliest efforts made towards the generalization of ideas, with the efforts of modern times. In the intellectual movement of centuries, whose influence on the extension of Cosmical contemplation has been defined in another portion of the present work,[27] the close of the thirteenth and the beginning of the fourteenth century were specially distinguished; but the *Opus majus* of Roger Bacon, the *Mirror of Nature* of Vincenzo de Beauvais, the Physical Geography (*Liber cosmographicus*) of Albertus Magnus, the Picture of the World (*Imago Mundi*) of Cardinal Petrus d'Alliaco (Pierre d'Ailly) are works, which, however powerfully they may have influenced the age in which they were written, do not fulfil by their contents the promise of their titles. Among the Italian opponents of Aristotle's physics, Bernardino Telesio of Cosenza is designated the founder of a rational science of nature. All the phenomena of inert matter are considered by him as the effects of two incorporeal principles (agencies or forces)—heat and cold. All forms of organic life—"ani-

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*mundi*), and which is decreased by distance, in accordance with the laws of light, and impels the planets in elliptic orbits (Compare Apelt, *Epochen der Gesch. der Menschheit.* bd. 1, s. 274.)

[27] *Cosmos*, vol. ii. p. 615–625.

mated" plants and animals—are the effect of these two ever divided forces, of which the one, heat, specially appertains to the celestial, and the other, cold, to the terrestrial sphere.

With yet more unbridled fancy, but with a profound spirit of enquiry, Giordano Bruno of Nola attempted to comprehend the whole universe, in three works,[28] entitled, *De la causa Principio e Uno; Contemplationi circa lo Infinito, Universo e Mondi innumerabili;* and *De Minimo et Maximo.* In the natural philosophy of Telesio, a contemporary of Copernicus, we recognise at all events the tendency to reduce the changes of matter to two of its fundamental forces, which, although "supposed to act from without," yet resemble the fundamental forces of attraction and repulsion in the dynamic theory of nature of Boscovich and Kant. The cosmical views of the philosopher of Nola are purely metaphysical, and do not seek the causes of sensuous phenomena in matter itself, but treat of "the infinity of space, filled with self-illumined worlds, of the animated condition of those worlds, and of the relations of the highest intelligence—God—to the universe."

Scantily endowed with mathematical knowledge, Giordano Bruno continued nevertheless to the period of his fearful martyrdom[29] an enthusiastic admirer of Copernicus, Tycho Brahe, and Kepler. He was contemporary with Galileo, but did not live to see the invention of the telescope by Hans Lippershey and Zacharias Jansen, and did not therefore witness the discovery of the "lesser Jupiter world," the phases of Venus, and the nebulæ. With bold confidence in what he terms the *lume interno*, *ragione naturale*, *altezza dell' intelletto* (force of intellect), he indulged in happy conjectures regarding the movement of the fixed stars, the planetary nature of comets, and the deviation from the spherical form observed in the figure of the earth.[30] Greek antiquity is also replete with uranological presentiments of this nature, which were realised in later times.

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[28] Compare the acute and learned commentary on the works of the Philosopher of Nola in the treatise, *Jordano Bruno* par Christian Bartholmèss, tom. ii. 1847, pp. 129, 149, and 201.

[29] He was burnt at Rome on the 17th of February, 1600, pursuant to the sentence "ut quam clementissime et citra sanguinis effusionem puniretur." Bruno was imprisoned six years in the *Piombi*, at Venice, and two years in the Inquisition at Rome. When the sentence of death was announced to him, Bruno, calm and unmoved, gave utterance to the following noble expression, "Majori forsitan cum timore sententiam in me fertis quam ego accipiam." When a fugitive from Italy, in 1580, he taught at Geneva, Lyons, Toulouse,

In the development of thought on cosmical relations, of which the main forms and epochs have been already enumerated, Kepler approached the nearest to a mathematical application of the theory of gravitation, more than seventy-eight years before the appearance of Newton's immortal work, *Principia Philosophiæ Naturalis*. For while the eclectic Simplicius only expressed in general terms "that the heavenly bodies were sustained from falling in consequence of the centrifugal force being superior to the inherent falling force of bodies and to the downward traction;" while Joannes Philoponus, a disciple of Ammonius Hermeas,

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Paris, Oxford, Marburg, Wittenberg (which he calls the Athens of Germany), Prague, and Helmstedt, where, in 1589, he completed the scientific instruction of Duke Henry Julius of Brunswick-Wolfenbüttel. Bartholmèss, tom. i. pp. 167–178. He also taught at Padua subsequently to 1592.

[30] Bartholmèss, tom. ii. pp. 219, 232, 370. Bruno carefully collected all the separate observations made on the celestial phenomenon of the sudden appearance, in 1572, of a new star in Cassiopeia. Much discussion has been directed in modern times to the relation existing between Bruno, his two Calabrian fellow-countrymen, Bernardino Telesio and Thomas Campanella, and the platonic cardinal, Nicolaus Krebs of Cusa; see *Cosmos*, p. 691, note.

ascribed the movement of the celestial bodies to "a primitive impulse, and the continued tendency to fall;" and while, as we have already observed, Copernicus defined only the general idea of gravitation, as it acts in the sun, as the centre of the planetary world, in the earth and in the moon, using these memorable words, "Gravitatem non aliud esse quam appetentiam quandam naturalem partibus inditam a divina providentia opificis universorum, ut in unitatem integritatemque suam sese conferant, in formam globi coëuntes;" Kepler in his introduction to the book, *De Stella Martis*,[31] was the first who gave *numerical* calculations of the forces of attraction reciprocally exercised upon each other, according to their relative masses, by the earth and moon. He distinctly adduces the tides as evidence[32] that the attractive force of the moon *(virtus*

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[31] "Si duo lapides in aliquo loco Mundi collocarentur propinqui invicem, extra orbem virtutis tertii cognati corporis; illi lapides ad similitudinem duorum Magneticorum corporum coirent loco intermedio, quilibet accedens ad alterum tanto intervallo, quanta est alterius *moles* in comparatione. Si luna et terra non retinerentur vi animali (!) aut alia aliqua æquipollente, quælibet in suo circuitu, Terra adscenderet ad Lunam quinquagesima quarta parte intervalli, Luna descenderet ad Terram quinquaginta tribus circiter partibus intervalli; ibi jungerentur, posito tamen quod substantia utriusque sit unius et ejusdem densitatis." Kepler, *Astronomia nova, seu Physica cœlestis de Motibus Stellæ Martis*, 1609. *Introd.* fol. v. On the older views regarding gravitation, see *Cosmos*, vol. ii. p. 691.

[32] "Si Terra cessaret attrahere ad se aquas suas, aquæ marinæ omnes elevarentur et in corpus Lunæ influerent. Orbis virtutis tractoriæ, quæ est in Luna, porrigitur usque ad terras, et prolectat aquas quacunque in verticem loci incidit sub Zonam torridam, quippe in occursum suum quacunque in verticem loci incidit, insensibiliter in maribus inclusis, sensibiliter ibi ubi sunt latissimi alvei Oceani propinqui, aquisque spaciosa reciprocationis libertas." (Kepler, l. c.) "Undas a Luna trahi ut ferrum a Magnete." . . . . *Kepleri Harmonice*

*tractoria)* extends to the earth; and that this force, similar to that exerted by the magnet on iron, would deprive the earth of its water if the former should cease to attract it. Unfortunately this great man was induced ten years afterwards, in 1619, probably from deference to Galileo, who ascribed the ebb and flow of the ocean to the rotation of the earth, to renounce his correct explanation, and depict the earth in the *Harmonice Mundi* as a living monster, whose whale-like mode of breathing occasioned the rise and fall of the ocean in recurring periods of sleeping and waking, dependant on solar time. When we remember the mathematical acumen that pervades one of the works of Kepler, and of which Laplace has already made honourable mention,[33] it is to be lamented that the discoverer of the three great laws of all planetary motion should not have advanced on the path whither he had been led by his views on the attraction of the masses of cosmical bodies.

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*Mundi*, libri quinque, 1619, lib. iv. cap. 7, p. 162. The same work which presents us with so many admirable views, among others, with the data of the establishment of the *third law* (that the squares of the periodic times of two planets are as the cubes of their mean distances), is distorted by the wildest flights of fancy on the respiration, nutrition, and heat of the *earth-animal*, on the soul, memory (*memoria animæ Terræ*), and creative imagination (*animæ Telluris imaginatio*) of this monster. This great man was so wedded to these chimeras, that he warmly contested his right of priority in the views regarding the *earth-animal*, with the mystic author of the *Macrocosmos*, Robert Fludd, of Oxford, who is reported to have participated in the invention of the thermometer. (*Harm. Mundi*, p. 252.) In Kepler's writings, the attraction of masses is often confounded with magnetic attraction. "Corpus solis esse magneticum. Virtutem, quæ Planetas movet, residere in corpore solis." *Stella Martis*, pars iii. cap. 32, 34. To each planet was ascribed a magnetic axis, which constantly pointed to one and the same quarter of the heavens. (Apelt, *Joh. Kepler's astron. Weltansicht*, 1849, s. 73.

[33] Compare *Cosmos*, p. 710 (and note).

Descartes, who was endowed with greater versatility of physical knowledge than Kepler, and who laid the foundation of many departments of mathematical physics, undertook to comprise the whole world of phenomena, the heavenly sphere and all that he knew concerning the animate and inanimate parts of terrestrial nature, in a work entitled *Traité du Monde*, and also *Summa Philosophiæ*. The organisation of animals, and especially that of man—a subject to which he devoted the anatomical studies of eleven years[34]—was to conclude the work. In his correspondence with Father Mersenne, we frequently find him complaining of his slow progress, and of the difficulty of arranging so large a mass of materials. The *Cosmos* which Descartes always called "his world," (son monde) was at length to have been sent to press at the close of the year 1633, when the report of the sentence passed by the Inquisition at Rome on Galileo, which was first made generally known four months afterwards, in October, 1633, by Gassendi and Bouillaud, at once put a stop to his plans, and deprived posterity of a great work, completed with much pains and infinite care. The motives that restrained him from publishing the *Cosmos* were, love of peaceful retirement in his secluded abode at Deventer, and a pious desire not to treat irreverentially the decrees pronounced by the Holy Chair, against the planetary movement of the earth.[35] In 1664, fourteen years after the death of the philosopher, some fragments were first printed under the singular title of *Le Monde, ou Traité de la Lumière*.[36] The three chapters which treat of light, scarcely, however, constitute a fourth part of the work; whilst those sections which originally belonged to the *Cosmos* of Descartes, and treated of the movement of the planets, and their distance from the sun, of terrestrial magnetism, the ebb and flow of the ocean, earthquakes, and volcanoes, have been transposed to the third and fourth portions of the celebrated work, *Principes de la Philosophie.*

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[34] See *La Vie de M. Descartes*, (par Baillet) 1691, P. 1, p. 197, and *Œuvres de Descartes*, publiées par Victor Cousin, tom. i. 1824, p. 101.

[35] *Lettres de Descartes au P. Mersenne, du* 19 *Nov.* 1633, *et du* 5 *Janvier* 1634. (Baillet, P. 1. pp. 244–247.)

[36] The Latin translation bears the title, *Mundus sive Dissertatio de Lumine ut et de aliis Sensuum Objectis primariis.* See Descartes, *Opuscula posthuma physica et mathematica.* Amst. 1704.

Notwithstanding its ambitious title, the *Cosmotheoros* of Huygens, which did not appear till after his death, scarcely deserves to be noticed in this enumeration of cosmological efforts. It consists of the dreams and fancies of a great man on the animal and vegetable worlds, of the most remote cosmical bodies, and especially of the modifications of form which the human race may there present. The reader might suppose he were perusing Kepler's *Somnium Astronomicum*, or Kircher's *Iter Extaticus.* As Huygens, like the astronomers of our own day, denied the presence of air and water in the moon,[37] he is much more embarrassed regarding the existence of inhabitants in the moon, than of those in the remoter planets, which he assumes to be "surrounded with vapours and clouds."

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[37] "Lunam aquis carere et aëre: Marium similitudinem in Luna nullam reperio. Nam regiones planas quæ montosis multo obscuriores sunt, quasque vulgo pro maribus haberi video et oceanorum nominibus insigniri, in his ipsis, longiore telescopio inspectis, cavitates exiguas inesse comperio rotundas, umbris intus cadentibus; quod maris superficiei convenire nequit; tum ipsi campi illi latiores non prorsus æquabilem superficiem præferunt, cum diligentius eas intuemur. Quod circa maria esse non possunt, sed materia constare debent minus candicante, quam quæ est partibus asperioribus in quibus rursus quædam viridiori lumine cæteras præcellunt." *Hugenii Cosmotheoros*, ed. alt. 1699, lib. 11, p. 114. Huygens conjectures however that Jupiter is agitated by much wind and rain, for "ventorum flatus ex illa nubium Jovialium mutabili facie cognoscitur," (lib. i. p. 69). These dreams of Huygens, regarding the inhabitants of remote planets, so unworthy of a man versed in exact mathematics, have, unfortunately, been revived by Emanuel Kant, in his admirable work *Allgemeine Naturgeschichte und Theorie des Himmels*, 1755 (s. 173–192).

The immortal author of the *Philosophiæ Naturalis Principia Mathematica* (Newton) succeeded in embracing the whole uranological portion of the *Cosmos* in the causal connexion of its phenomena, by the assumption of one all-controlling fundamental moving force. He first applied physical astronomy to solve a great problem in mechanics, and elevated it to the rank of a mathematical science. The quantity of matter in every celestial body gives the amount of its attracting force; a force which acts in an inverse ratio to the square of the distance, and determines the amount of the disturbances, which not only the planets but all the bodies in celestial space exercise on each other. But the Newtonian theory of gravitation, so worthy of our admiration from its simplicity and generality, is not limited in its cosmical application to the uranological sphere, but comprises also telluric phenomena, in directions not yet fully investigated; it affords the clue to the periodic movements in the ocean and the atmosphere;[38] and solves the problems of capillarity, of endosmosis, and of many chemical, electro-magnetic, and organic processes. Newton,[39] even distinguished *the attraction of masses*, as manifested in the motion of cosmical bodies and in the phenomena of the tides, from *molecular attraction*, which acts at infinitely small distances and in the closest contact.

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[38] See Laplace (*des oscillations de l'atmosphère, du flux solaire et lunaire*) in the *Mécanique Céleste*, livre iv. and in the *Exposition du Syst. du Monde*, 1824, pp. 291–296.

[39] Adjicere jam licet de spiritu quodam subtilissimo corpora crassa pervadente et in iisdem latente, cujus vi et actionibus particulæ corporum ad *minimas distantias* se mutuo *attrahunt* et contiguæ factæ cohærent. Newton, *Principia Phil. Nat.* (ed. Le Sueur et Jacquier, 1760) Schol. gen., t. iii. p. 676, compare also Newton's *Opticks*, (ed. 1718). *Query* 31, pp. 305, 353, 367, 372. (Laplace, *Syst. du Monde*, p. 384, and *Cosmos*, p. 44.)

Thus we see that among the various attempts which have been made to refer whatever is unstable in the sensuous world to a single fundamental principle, the theory of gravitation is the most comprehensive and the richest in cosmical results. It is indeed true, that notwithstanding the brilliant progress that has been made in recent times in stœchiometry (the art of calculating with chemical elements and in the relations of volume of mixed gases) all the physical theories of matter have not yet been referred to mathematically-determinable principles of explanation. Empirical laws have been recognized, and by means of the extensively diffused views of the atomic or corpuscular philosophy, many points have been rendered more accessible to mathematical investigation; but owing to the unbounded heterogeneousness of matter and the manifold conditions of aggregation of particles, the proofs of these empirical laws cannot as yet by any means be developed from the theory of contact-attraction, with that certainty which characterizes the establishment of Kepler's three great empirical laws derived from the theory of the attraction of masses or gravitation.

At the time, however, that Newton recognized all movements of the cosmical bodies to be the results of one and the same force, he did not, like Kant, regard gravitation as an essential property of bodies;[40] but considered it either as the result of some higher and still unknown power, or of "the centrifugal force of the æther, which fills the realms of space, and is rarer within bodies, but increases in density outwards. The latter view is set forth in detail in a letter to Robert Boyle[41] (dated February 28, 1678), which ends with the

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[40] Hactenus phænomena cœlorum et maris nostri per vim gravitatis exposui, sed causam gravitatis nondum assignavi. Oritur utique hæc vis a causa aliqua, quæ penetrat ad usque centra solis et planetarum, sine virtutis diminutione; quæque agit non pro quantitate superficierum particularum, in quas agit (ut solent causæ mechanicæ), sed pro quantitate materiæ solidæ.—Rationem harum gravitatis proprietatum ex phænomenis nondum potui deducere et hypotheses non fingo. Satis est quod gravitas revera existat et agat secundum leges a nobis expositas. Newton, *Principia Phil. Nat.*, p. 676.

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"To tell us that every species of things is endowed with an occult specific quality, by which it acts and produces manifest effects, is to tell us nothing; but to derive two or three general principles of motion from phenomena, and afterwards to tell us how the properties and actions of all corporeal things follow from those manifest principles, would be a very great step in philosophy, though the causes of those principles were not yet discovered: and therefore I scruple not to propose the principles of motion, and leave their causes to be found out." Newton's *Opticks*, p. 377. In a previous portion of the same work, at query 31, p. 351, he writes as follows: "Bodies act one upon another by the attraction of gravity, magnetism, and electricity; and it is not improbable that there may be more attractive powers than these. How these attractions may be performed I do not here consider. What I call attraction may be performed by *impulse*, or by some other means unknown to me. I use that word here to signify only in general any force by which bodies tend towards one another, whatsoever be the cause."

[41] "I suppose the rarer æther within bodies, and the denser without them." *Operum Newtoni*, tomus iv. (ed. 1782, Sam. Horsley,) p. 386. The above observation was made in reference to the explanation of the discovery made by Grimaldi of the *diffraction* or inflection of light. At the close of Newton's letter to Robert Boyle, February 1678, p. 394, he says: "I shall set down one conjecture more which came into my mind: it is about the cause of gravity." . . . . His correspondence with Oldenburg (December 1675) shows that the great philosopher was not at that time averse to the "æther hypotheses." According to these views, the impulse of *material* light causes the æther to vibrate; but the vibrations of the æther alone, which has some affinity to a nervous fluid, does not generate light. In reference to the contest with Hooke, consult Horsley, t. iv. pp. 378–380.

words, "I seek the cause of gravity in the æther." Eight years afterwards, as we learn from a letter he wrote to Halley, Newton entirely relinquished this hypothesis of the rarer and denser æther.[42] It is especially worthy of notice that in 1717, nine years before his death, he should have deemed it necessary expressly to state in the short preface to the second edition of his Optics, that he did not by any means consider gravity as an "essential property of bodies";[43] whilst Gilbert, as early as 1600, regarded magnetism as a force inherent in all matter. So undetermined was even Newton, the profound and experienced thinker, regarding the "ultimate mechanical cause" of all motion.

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[42] See Brewster's *Life of Sir Isaac Newton*, pp. 303–305.

[43] Newton's words "not to take gravity for an essential property of bodies" in the "Second Advertisement" contrast with his remarks on the forces of attraction and repulsion, which he ascribes to *all* molecular particles, in order, according to the theory of emission, to explain the phenomena of the refraction and repulsion of the rays of light from reflecting surfaces "without their actual contact." (Newton, *Opticks*, book ii., prop. 8, p. 241, and Brewster, *Op. cit.*, p. 301.) According to Kant, (see *Die Metaphysischen Anfangsgründe der Naturwissenschaft*, 1800, s. 28,) we cannot conceive the existence of matter without these forces of attraction and repulsion. All physical phenomena are therefore reduced by him, as previously by Goodwin Knight (*Philos. Transact.* 1748, p. 264), to the conflict of two elementary forces. In the atomic theories which were diametrically opposed to Kant's dynamic views, the force of attraction was referred, in accordance with a view specially promulgated by Lavoisier, to the discrete solid elementary molecules of which all bodies are supposed to consist; while the force of repulsion was attributed to the *atmospheres of heat* surrounding all elementary corpuscles. This hypothesis, which regards the so-called *caloric* as a constantly expanded matter, assumes the existence of two elementary substances, as in the mythical idea of two kinds of æther. (Newton, *Opticks*, query 28, p. 339.) Here the question arises, what causes this caloric matter to expand? Considerations on the density of molecules in comparison with that of their aggregates (the entire body) lead, according to atomic hypotheses, to the result, that the distance between elementary corpuscles is far greater than their diameters.

It is indeed a brilliant effort, worthy of the human mind, to comprise, in one organic whole, the entire science of nature from the laws of gravity to the formative impulse (nisus formativus) in animated bodies; but the present imperfect state of many branches of physical science offers innumerable difficulties to the solution of such a problem. The imperfectibility of all empirical science, and the boundlessness of the sphere of observation, render the task of explaining the forces of matter by that which is variable in matter, an impracticable one. What has been already perceived by no means exhausts that which is perceptible. If, simply referring to the progress of science in modern times, we compare the imperfect physical knowledge of Gilbert, Robert Boyle, and Hales, with that of the present day, and remember that every few years are characterized by an increasing rapidity of advance, we shall be better able to imagine the periodical and endless changes which all physical sciences are destined to undergo. New substances and new forces will be discovered.

Although many physical processes, as those of light, heat and electro-magnetism, have been rendered accessible to a mathematical investigation, by being reduced to motion or vibrations, we are still without a solution to those often mooted and perhaps insolvable problems: the cause of chemical differences of matter; the apparently irregular distribution of the planets in reference to their size, density, the inclination of their axes, the eccentricity of their orbits, and the number and distance of their satellites; the configuration of continents, and the position of their highest mountain chains. Those relations in space, which we have referred to merely by way of illustration, can at present be regarded only as something existing in nature, as a fact, but which I cannot designate as merely causal, because their causes and mutual connection have not yet been discovered. They are the result of occurrences in the realms of space coeval with the formation of our planetary system, and of geognostic processes in the upheaval of the outer strata of the earth into continents and mountain chains. Our knowledge of the primeval ages of the world's physical history does not extend sufficiently far to allow of our depicting the present condition of things as one of development.[44]

Wherever the causal connection between phenomena has not yet been fully recognized, the doctrine of the Cosmos, or the physical description of the universe, does not constitute a distinct branch of physical science. It rather embraces the whole domain of nature, the phenomena of both the celestial and terrestial spheres — but embraces it only under the single point of view of efforts made towards the knowledge of the universe as a whole.[45] As in the "exposition of past events in the moral and political world, the historian[46] can only divine the plan of the government of the world, according to human views, through the signs which are presented to him, and not by direct insight;" so also the enquirer into nature, in his investigation of cosmical relations, feels himself penetrated by a profound consciousness that the fruits hitherto yielded by direct observation and by the careful analysis of phenomena, are far from having exhausted the number of impelling, producing, and formative forces.

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[44] *Cosmos*, pp. 79-82.

[45] *Op. cit.* pp. 36, 38–44.

[46] Wilhelm von Humboldt, *Gesammelte Werke*, bd. i. s. 23.

## A.

### RESULTS OF OBSERVATIONS IN THE URANOLOGICAL PORTION OF THE PHYSICAL DESCRIPTION OF THE WORLD.

We again commence with the depths of cosmical space, and the remote sporadic starry systems, which appear to telescopic vision as faintly shining *nebulæ*. From these we gradually descend to the double stars, revolving round one common centre of gravity, and which are frequently bicoloured, to the nearer starry strata, one of which appears to enclose our own planetary system; passing thence to the air-and-ocean-girt terrestrial spheroid which we inhabit. We have already indicated in the introduction to the *General Delineation of Nature*,[1] that this arrangement of ideas is alone suited to the character of a work on the Cosmos, since we cannot here, in accordance with the requirements of direct sensuous contemplation, begin with our own terrestrial abode, whose surface is animated by organic forces, and pass from the apparent to the true movements of cosmical bodies.

The *uranological*, when opposed to the *telluric* domain of the Cosmos, may be conveniently separated into two divisions, one of which comprises *astrognosy*, or the region of the *fixed stars*, and the other our *solar and planetary system*. It is unnecessary here to describe the imperfect and unsatisfactory nature of such a nomenclature and such classifications. Names were introduced into the physical sciences before the differences of objects and their strict limitations were sufficiently known.[2] The most important point, however, is the connection of ideas, and the order in which the objects are to be considered. Innovations in the nomenclature of groups, and a deviation from the meanings hitherto attached to well-known names, only tend to distract and confuse the mind.

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[1] *Cosmos*, pp. 62–66.

[2] *Op. cit.* pp. 38, 39.

## *a*. ASTROGNOSY. (The Domain of the Fixed Stars.)

Nothing is stationary in space. Even the fixed stars move, as Halley[3] endeavoured to show in reference to Sirius, Arcturus, and Aldebaran, and as in modern times has been incontrovertibly proved with respect to many others. The bright star Arcturus has, during the 2100 years (since the times of Aristillus and Hipparchus) that it has been observed, changed its position in relation to the neighbouring fainter stars 2½ times the moon's diameter. Encke remarks "that the star μ Cassiopeiæ appears to have moved 3½ lunar diameters, and 61 Cygni about 6 lunar diameters, if the ancient observations correctly indicated its position." Conclusions based on analogy justify us in believing that there is everywhere progressive, and perhaps also rotatory motion. The term "fixed stars" leads to erroneous preconceptions; it may have referred, in its earliest meaning among the Greeks, to the idea of the stars being rivetted into the crystal vault of heaven; or, subsequently, in accordance with the Roman interpretation, it may indicate fixity or immobility. The one idea involuntarily led to the other. In Grecian antiquity, in an age at least as remote as that of Anaximenes of the Ionic school, or of Alcmeon the Pythagorean, all stars were divided into *wandering* (*ἄστρα πλανώμενα* or *πλανητά*) and *non-wandering* fixed stars (*ἀπλανεῖς ἀστέρες* or *ἀπλανῆ ἄστρα*).[4] Besides this generally adopted designation of the fixed stars, which Macrobius in his *Somnium Scipionis*, latinized by *Sphæra aplanes*,[5] we frequently meet in Aristotle (as if he wished to introduce a new technical term) with the phrase *rivetted* stars, ἐνδεδεμένα ἄστρα, instead of ἀπλανῆ,[6] as a designation for fixed stars. From this form of speech arose the expressions of *sidera infixa cælo* of Cicero, *stellas quas putamus affixas* of Pliny, and *astra fixa* of Manilius, which corresponds with our term fixed stars.[7] This idea of fixity leads to the secondary idea of immobility, of persistence in one spot, and thus the original signification of the expressions *infixum* or *affixum sidus*, was gradually lost sight of in the Latin translations of the middle ages, and the idea of immobility alone retained. This is already apparent in a highly rhetorical passage of Seneca, regarding the possibility of discovering new planets, in which he says (*Nat. Quæst.*, vii. 24): "Credis autem in hoc maximo et pulcherrimo corpore inter innumerabiles stellas, quæ noctem decore vario distinguunt, quæ aëra minime vacuum et inertem esse patiuntur, quinque solas esse, quibus exercere se liceat; *ceteras stare fixum et immobilem populum?*" "And dost thou believe that in this so great and splendid body, amongst innumerable stars, which by their various beauty adorn the night, not suffering the air to remain void and unprofitable, that there should be only five stars to whom it is permitted to be in motion, whilst all the rest remain a fixed and immoveable multitude." This fixed and immoveable multitude is nowhere to be found.

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[3] Halley, in the *Philos. Transact. for* 1717, vol. xxx. p. 736.

[4] Pseudo-Plut., *de plac. Philos.*, ii. 15, 16; Stob. *Eclog. phys.*, p. 582; Plato in the *Timæus*, p. 40.

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[5] Macrob., *Somn. Scip.*, i. 9–10; *stellæ inerrantes*, in Cicero *de nat. Deorum*, iii. 20.

[6] The principal passage in which we meet with the technical expression ἐνδεδεμένα ἄστρα, is in Aristot. *de Cælo*, ii. 8, p. 289, l. 34, p. 290, l. 19, Bekker. This altered nomenclature forcibly attracted my attention in my investigations into the optics of Ptolemy, and his experiments on refraction. Professor Franz, to whose philological acquirements I am indebted for frequent aid, reminds me that Ptolemy (*Syntax*, vii. 1,) speaks of the fixed stars as affixed or rivetted; ὥσπερ προσπεφυκότες. Ptolemy thus objects to the expression σφαῖρα ἀπλανής (*orbis inerrans*); "in as far as the stars constantly preserve their relative distances they might rightly be termed ἀπλανεῖς; but in as far as the sphere in which they complete their course, and in which they seem to have grown, as it were, has an independent motion, the designation ἀπλανής is inappropriate if applied to the sphere."

[7] Cicero, *de nat. Deorum*, i. 13; Plin. ii. 6 and 24; Manilius, ii. 35.

In order the better to classify the main results of actual observations, and the conclusions or conjectures to which they give rise, in the description of the universe, I will separate the astrognostic sphere into the following sections:—

I. The considerations on the realms of space and the bodies by which they appear to be filled.

II. Natural and telescopic vision, the scintillation of the stars, the velocity of light, and the photometric experiments on the intensity of stellar light.

III. The number, distribution, and colour of the stars; the stellar swarms, and the milky way which is interspersed with a few nebulæ.

IV. The newly appeared and periodically changing stars, and those that have disappeared.

V. The proper motion of the fixed stars, the problematical existence of dark cosmical bodies; the parallax and measured distance of some of the fixed stars.

VI. The double stars, and the period of their revolution round a common centre of gravity.

VII. The nebulæ which are interspersed in the Magellanic clouds with numerous stellar masses, the black spots (coal-bags) in the vault of heaven.

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# I.

## THE REALMS OF SPACE, AND CONJECTURES REGARDING THAT WHICH APPEARS TO OCCUPY THE SPACE INTERVENING BETWEEN THE HEAVENLY BODIES.

THAT portion of the physical description of the universe which treats of what occupies the distant regions of the heavens, filling the space between the globular cosmical bodies, and is imperceptible to our organs, may not unaptly be compared to the mythical commencement of ancient history. In infinity of space, as well as in eternity of time, all things are shrouded in an uncertain and frequently deceptive twilight. The imagination is here doubly impelled to draw from its own fulness, and to give outline and permanence to these indefinite changing forms.[8] This observation will, I trust, suffice to exonerate me from the reproach of confounding that which has been reduced to mathematical certainty, by direct observation or measurement, with that which is founded on very imperfect induction. Wild reveries belong to the romance of physical astronomy; yet the mind familiar with scientific labours, delights in dwelling on subjects such as these, which, intimately connected with the present condition of science, and with the hopes which it inspires, have not been deemed unworthy of the earnest attention of the most distinguished astronomers of our day.

By the influence of gravitation, or general gravity, as well as by light and radiating heat,[9] we are brought in contact, as we may with great probability assume, not only with our own Sun, but also with all the other luminous suns of the firmament. The important discovery of the appreciable resistance which a fluid filling the realms of space is capable of opposing to a comet having a period of revolution of five years, has been perfectly confirmed by the exact accordance of numerical relations. Conclusions based upon analogies may fill up a portion of the vast chasm which separates the certain results of a mathematical natural philosophy from conjectures verging on the extreme, and therefore obscure and barren confines of all scientific development of mind.

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[8] *Cosmos*, vol. i. p. 71. (Compare the admirable observations of Encke, *Ueber die Anordnung des Sternsystems*, 1844, s. 7.)

[9] *Cosmos*, vol. i. pp. 145, 146.

From the infinity of space,—an infinity, however, doubted by Aristotle,[10]—follows the idea of its immeasurability. Separate portions only have been rendered accessible to measurement, and the numerical results, which far exceed the grasp of our comprehension, become a source of mere puerile gratification to those who delight in high numbers, and imagine that the sublimity of astronomical studies may be heightened by astounding and terrific images of physical magnitude. The distance of 61 Cygni from the Sun is 657000 semi-diameters of the Earth's orbit; a distance which light takes rather more than ten years to traverse, whilst it passes from the Sun to the Earth in 8′ 17″·78. Sir John Herschel conjectures, from his ingenious combination of photometric calculations,[11] that if the stars in the great circle of the Milky Way which he saw in the field of his twenty-feet telescope were newly-arisen luminous cosmical bodies, they would have required 2000 years to transmit to us the first ray of light. All attempts to present such numerical relations fail, either from the immensity of the unit by which they must be measured, or from the high number yielded by the repetition of this unit Bessel[12] very truly observes that "the distance which light traverses in a year is not more appreciable to us than the distance which it traverses in ten years. Therefore every endeavour must fail to convey to the mind any idea of a magnitude exceeding those that are accessible on the earth." This overpowering force of numbers is as clearly manifested in the smallest organisms of animal life as in the milky way of those self-luminous suns which we call fixed stars. What masses of Polythalamiæ are inclosed, according to Ehrenberg, in one thin stratum of chalk! This eminent investigator of nature asserts that one cubic inch of the Bilin polishing slate, which constitutes a sort of mountain cap forty feet in height, contains 41000 millions of the microscopic *Galionella distans;* while the same volume contains more than 1 billion 750000 millions of distinct individuals of *Galionella ferruginea.*[13] Such estimates remind us of the treatise named *Arenarius* (ψαμμίτης) of Archimedes—of the sand-grains which might fill the universe of space! If the starry heavens, by incalculable numbers, magnitude, space, duration, and length of periods, impress man with the conviction of his own insignificance, his physical weakness, and the ephemeral nature of his existence; he is, on the other hand, cheered and invigorated by the consciousness of having been enabled, by the application and development of intellect, to investigate very many important points in reference to the laws of Nature and the sidereal arrangement of the universe.

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[10] Aristot. *de Cælo*, 1, 7, p. 276; Bekker.

[11] Sir John Herschel, *Outlines of Astronomy*, 1849, § 803, p. 541.

Although not only the propagation of light, but also a special form of its diminished intensity, the resisting medium acting on the periods of revolution of Encke's comet, and the evaporation of many of the large tails of comets, seem to prove that the regions of space which separate cosmical bodies are not void,[14] but filled with some kind of matter; we must not omit to draw attention to the fact, that among the now current but indefinite expressions of "*the air of heaven*," "*cosmical* (non-luminous) *matter*," and "*ether*," the latter, which has been transmitted to us from the earliest antiquity of Southern and Western Asia, has not always expressed the same idea. Among the natural philosophers of India, ether (*âkâ'sa*) was regarded as belonging to the *pantschatâ*, or five elements, and was supposed to be a fluid of infinite subtlety, pervading the whole universe, and constituting the medium of exciting life, as well as of propagating sound.[15] Etymologically considered, *âkâ'sa* signifies, according to Bopp, "luminous or shining, and bears, therefore, in its fundamental signification, the same relation to the 'ether' of the Greeks as *shining* does to burning."

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[12] Bessel, in Schumacher's *Jahrbuch für* 1839, s. 50.

[13] Ehrenberg, *Abhandl. der Berl. Akad.*, 1838, s. 59; also in his *Infusionsthiere*, s. 170.

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[14] Aristotle (*Phys. Auscult.*, iv. 6–10, pp. 213–217, Bekker.) proves, in opposition to Leucippus and Democritus, that there is no *unfilled* space—no *vacuum* in the universe.

[15] *Akâ'sa* signifies, according to Wilson's Sanscrit Dictionary, "the subtle and ethereal fluid supposed to fill and pervade the universe, and to be the peculiar vehicle of life and sound." "The word *âkâ'sa* (luminous, shining) is derived from the root *kâ's* (to shine), to which is added the preposition *â*. The quintuple of all the elements is called *pantschatâ*, or *pantschatra*, and the dead are, singularly enough, designated as those who have been resolved into the five elements (*prâpta pantschatra*). Such is the interpretation given in the text of Amarakoscha, Amarasinha's Dictionary."—(Bopp.) Colebrooke's admirable treatise on the Sânkhya Philosophy, treats of these five elements; see *Transact. of the Asiat. Soc.*, vol. i. Lond. 1827, p. 31. Strabo refers, according to Megasthenes, (xv. § 59, p. 713, Cas.) to the all-forming fifth element of the Indians, without, however, naming it.

In the dogmas of the Ionic philosophy of Anaxagoras and Empedocles, this ether (*αἰθήρ*) differed wholly from the actual (denser) vapour-charged air (*ἀήρ*) which surrounds the earth, and "probably extends as far as the moon." It was of "a fiery nature, a brightly-beaming, pure fire-air,[16] of great subtlety and eternal serenity." This definition perfectly coincides with its etymological derivation from *αἴθειν* to burn, for which Plato and Aristotle, from a predilection for mechanical views, singularly enough substituted another (*ἀεὶθεῖν*), on account of the constancy of the revolving and rotatory movement.[17] The idea of the subtlety and tenuity of the upper ether does not appear to have resulted from a knowledge that the air on mountains is purer and less charged with the heavy vapours of the earth, or that the density of the strata of air decreases with their increased height. In as far as the elements of the ancients refer less to material differences of bodies, or even to their simple nature (their incapacity of being decomposed), than to mere *conditions of matter*, the idea of the upper ether (the fiery air of heaven) has originated in the primary and normal contraries of *heavy* and *light*, *lower* and *upper*, *earth* and *fire*. These extremes are separated by two *intermediate elementary* conditions, of which the one, water, approximates most nearly to the heavy earth, and the other, air, to the lighter element of fire.[18]

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[16] Empedocles, v. 216, calls the ether *παμφανόων*, brightly-beaming, and therefore self-luminous.

[17] Plato, *Cratyl.* 410 B., where we meet with the expression *ἀειθεὴρ*. Aristot. de *Cœlo*, 1, 3, p. 270, Bekk. says in opposition to Anaxagoras: *αἰθέρα προσωνόμασαν τὸν ἀνωτάτω τόπον, ἀπὸ τοῦ θεῖν ἀεὶ τὸν ἀΐδιον χρόνον θέμενοι τὴν επωνυμίαν αὐτῷ. Ἀναξαγόρας δέ κατακέχρηται τῷ ονόματι τούτῳ οὐ καλῶς· ὀνομάζει γὰρ αἰθέρα ἀντὶ πυρός.* We find this more circumstantially referred to in Aristot. *Meteor.*, 1, 3, p. 339, lines 21-34, Bekk.: "The so-called ether has an ancient designation, which Anaxagoras seems to identify with fire; for, according to him, the upper region is full of fire, and to be considered as ether; in which, indeed, he is correct. For the ancients appear to have regarded the body which is in *a constant state of movement*, as possessing a divine nature, and therefore called it ether, a substance with which we have nothing analogous. Those, however, who hold the space surrounding bodies to be fire no less than the bodies themselves, and who look upon that which lies between the earth and the stars as air, would probably relinquish such childish fancies if they properly investigated the results of the latest researches of mathematicians." (The same etymology of this word, implying rapid revolution, is referred to by the Aristotelian, or Stoic, author of the work *De Mundo*, cap. 2, p. 392, Bekk.) Professor Franz has correctly remarked, "that the play of words in the designation of bodies *in eternal motion* (*σῶμα ἀεὶ θέον*) and of *the divine* (*θεῖον*) alluded to in the *Meteorologica*, is strikingly characteristic of the Greek type of imagination,

Considered as a medium filling the regions of space, the ether of Empedocles presents no other analogies excepting

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and affords additional evidence of the inaptitude of the ancients for etymological inquiry." Professor Buschmann calls attention to a Sanscrit term, *âschtra*, ether or the atmosphere, which looks very like the Greek αἰθήρ, with which it has been compared by Vans Kennedy, in his *Researches into the Origin and Affinity of the principal Languages of Asia and Europe*, 1828, p. 279. This word may also be referred to the root (*as*, *asch*) to which the Indians attach the signification of shining or beaming.

[18] Aristot. *de Cœlo*, iv. 1, and 3–4, pp. 308, and 311–312, Bekk. If the Stagirite withholds from ether the character of a fifth element, which indeed is denied by Ritter (*Geschichte der Philosophie*, th. iii. s. 259), and by Martin (*Etudes sur le Timée de Platon*, t. ii. p. 150); it is only because, according to him, ether, as a *condition of matter*, has no contrary. (Compare Biese, *Philosophie des Aristotiles*, bd. xi. s. 66.) Amongst the Pythagoreans, ether, as a fifth element, was represented by the fifth of the regular bodies, the *dodecahedron*, composed of twelve pentagons. (Martin, t. ii pp. 245–250.)

those of subtlety and tenuity with the ether, by whose transverse vibrations modern physicists have succeeded so happily in explaining, on purely mathematical principles, the propagation of light, with all its properties of double refraction, polarisation, and interference. The natural philosophy of Aristotle further teaches that the ethereal substance penetrates all the living organisms of the earth—both plants and animals; that it becomes in these the principle of vital heat, the very germ of a psychical principle, which, uninfluenced by the body, stimulates men to independent activity.[19] These visionary opinions draw down ether from the higher regions of space to the terrestrial sphere, and represent it as a highly rarefied substance constantly penetrating through the atmosphere and through solid bodies; precisely similar to the vibrating light-ether of Huygens, Hooke, and modern physicists. But what especially distinguishes the older Ionic from the modern hypothesis of ether, is the original assumption of luminosity, a view, however, not entirely advocated by Aristotle. The upper fire-air of Empedocles is expressly termed *brightly radiating* (*παμφανόων*), and is said to be seen by the inhabitants of the earth in certain phenomena, gleaming brightly through fissures and chasms (*χάσματα*) which occur in the firmament.[20]

The numerous investigations that have been made in recent times regarding the intimate relation between light, heat, electricity, and magnetism, render it far from improbable that, as the transverse vibrations of the ether which fills the regions of space give rise to the phenomena of light, the thermal and electro-magnetic phenomena may likewise have their origin in analogous kinds of motion (currents). It is reserved for future ages to make great discoveries in reference to these subjects. Light, and radiating heat, which is inseparable from it, constitute a main cause of motion and organic life, both in the non-luminous celestial bodies, and on the surface of our planet.[21] Even far from its surface, in the interior of the earth's crust, penetrating heat calls forth electro-magnetic currents, which exert their exciting influence on the combinations and decompositions of matter,—on all formative agencies in the mineral kingdom—on the disturbance of the equilibrium of the atmosphere,—and on the functions of vegetable and animal organisms. If electricity moving in currents develops magnetic forces, and if, in accordance with an early hypothesis of Sir William Herschel,[22] the sun itself is in the condition of "a perpetual northern light," (I should rather say of an electro-magnetic storm), we should seem warranted in concluding that solar light, transmitted in the regions of space by vibrations of ether, may be accompanied by electro-magnetic currents.

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[19] See the proofs collected by Biese, *op. cit.*, bd. xi. s. 93.

[20] *Cosmos*, vol. i. p 143.

Direct observations on the periodic changes in the declination, inclination, and intensity of terrestrial magnetism, have, it is true, not yet shown with certainty that these conditions are affected by the different positions of the sun or moon, notwithstanding the latter's contiguity to the earth. The magnetic polarity of the earth exhibits no variations that can be referred to the sun, or which perceptibly affect the precession of the equinoxes.[23] The remarkable rotatory or oscillatory motion of the radiating cone of light of Halley's comet, which Bessel observed from the 12th to the 22nd of October, 1835, and endeavoured to explain, led this great astronomer to the conviction that there existed a *polar force*, "whose action differed considerably from gravitation or the ordinary attracting force of the sun; since those portions of the comet which constitute the tail are *acted upon by a repulsive force proceeding from the body of the sun*."[24] The splendid comet of 1744, which was described by Heinsius, led my deceased friend to similar conjectures.

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[21] Compare the fine passage on the influence of the sun's rays, in Sir John Herschel's *Outlines of Astronomy*, p. 237: "By the vivifying action of the sun's rays, vegetables are enabled to draw support from inorganic matter, and become, in their turn, the support of animals and of man, and the sources of those *great deposits of dynamical efficiency which are laid up for human use in our coal strata.* By them the waters of the sea are made to circulate in vapour through the air, and irrigate the land, producing springs and rivers. By them are produced all disturbances of the chemical equilibrium of the elements of nature, which, by a series of compositions and decompositions, give rise to new products, and originate a transfer of materials."

[22] *Philos. Transact.* for 1795, vol. lxxxv. p. 318; John Herschel, *Outlines of Astr.*, p. 238; see also *Cosmos*, vol. i. p. 183.

*The actions of radiating heat* in the regions of space are regarded as less problematical than electro-magnetic phenomena. According to Fourier and Poisson, the temperature of the regions of space is the result of radiation of heat from the sun and *all* astral bodies, minus the quantity lost by absorption in traversing the regions of space filled with ether.[25] Frequent mention is made in antiquity by the Greek and Roman[26] writers of this *stellar heat;* not only because, from a universally prevalent assumption, the stars appertained to the region of the fiery ether, but because they were supposed to be themselves of a fiery nature[27]—the fixed stars and the sun being, according to the doctrine of Aristarchus of Samos, of one and the same nature. In recent times, the observations of the above-mentioned eminent French mathematicians, Fourier and Poisson, have been the means of directing attention to the average determination of the temperature of the regions of space; and the more strongly since the importance of such determinations on account of the radiation of heat from the earth's surface towards the vault of heaven, has at length been appreciated in their relation to all thermal conditions, and to the very habitability of our planet. According to Fourier's *Analytic Theory of Heat*, the temperature of celestial space (*des espaces planétaires ou célestes*) is rather below the mean temperature of the poles, or even perhaps below the lowest degree of cold hitherto observed in the polar regions. Fourier estimates it at from — 58° to — 76° (from — 40° to — 48° Reaum.). The icy pole (*pôle glacial*), or the point of the greatest cold, no more corresponds with the terrestrial pole than does the *thermal equator*, which connects together the hottest points of all meridians with the geographical equator. Arago concludes, from the gradual decrease of mean temperatures, that the degree of cold at the northern terrestrial pole is — 13°, if the maximum cold observed by Captain Back at Fort Reliance (62° 46′ lat.) in January, 1834, were actually — 70° (— 56°·6 Cent., or — 45°·3 Reaum.).[28] The

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[23] See Bessel, in Schumacher's *Astr. Nachr.*, bd. xiii. 1836, no. 300, s. 201.

[24] Bessel, *op. cit.*, s. 186–192, 229.

[25] Fourier, *Théorie analytique de la Chaleur*, 1822, p. ix. (*Annales de Chimie et de Physique*, tom. iii. 1816, p. 350; tom. iv. 1817, p. 128; tom. vi. 1817, p. 259; tom. xiii. 1820, p. 418). Poisson, in his *Théorie mathématique de la Chaleur* (§ 196, p. 436, § 200, p. 447, and § 228, p. 521), attempts to give the numerical estimates of the stellar heat (*chaleur stellaire*) lost by absorption in the ether of the regions of space.

[26] On the heating power of the stars, see Aristot. *de Meteor.*

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1, 3, p. 340, lin. 28; and on the elevation of the atmospheric strata at which heat is at the minimum, consult Seneca in *Nat. Quæst.*, ii. 10: "Superiora enim aëris calorem vicinorum siderum sentiunt."

[27] Plut. *de plac. Philos.*, ii. 13.

[28] Arago, *Sur la température du Pôle et des espaces célestes* in the *Annuaire du Bureau des Long. pour* 1825, p. 189, *et*

lowest temperature that, as far as we know, has as yet been observed on the earth, is probably that noted by Neveroff, at Jakutsk, (62° 2′ lat.) on the 21st of January, 1838. The instruments used in this observation were compared with his own by Middendorff, whose operations were always conducted with extreme exactitude. Neveroff found the temperature on the day above named to be — 76° (or — 48° Reaum.).

Among the many grounds of uncertainty in obtaining a numerical result for the thermal condition of the regions of space, must be reckoned that of our inability at present to ascertain the mean of the temperatures of the poles of greatest cold of the two hemispheres, owing to our insufficient acquaintance with the meteorology of the antarctic pole, from which the mean annual temperature must be determined. I attach but little

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*pour* 1834, p. 192; also Saigey, *Physique du Globe*, 1832, pp. 60–76. Swanberg found, from considerations on refraction, that the temperature of the regions of space was — 58°·5. Berzelius, *Jahresbericht für* 1830, s. 54. Arago, from polar observations, fixed it at — 70°; and Pectet at — 76°. Saigey, by calculating the decrease of heat in the atmosphere, from 367 observations made by myself in the chain of the Andes and in Mexico, found it — 85°; and from thermometrical measurements made at Mont Blanc, and during the aeronautic ascent of Gay-Lussac — 107°·2. Sir John Herschel (*Edinburgh Review*, vol. 87, 1848, p. 223) gives it at — 132°. We feel considerable surprise, and have our faith in the correctness of the methods hitherto adopted somewhat shaken, when we find that Poisson, notwithstanding that the mean temperature of Melville Island (74° 47′ N. Lat.) is — 1° 66′, gives the mean temperature of the regions of space at only 8°·6, having obtained his data from purely theoretical premises, according to which the regions of space are warmer than the outer limits of the atmosphere (see the work already referred to, § 227, p. 520); while Pouillet states it, from actinometric experiments, to be as low as — 223°·6. See *Comptes rendus de l'Académie des Sciences*, tom. vii. 1838, pp. 25–65 physical probability to the hypothesis of Poisson, that the different regions of space must have a very various temperature, owing to the unequal distribution of heat-radiating stars, and that the earth, during its motion with the whole solar system, receives its internal heat from without, while passing through hot and cold regions.[29]

The question whether the thermal conditions of the celestial regions, and the climates of individual portions of space, have suffered important variations in the course of ages, depends mainly on the solution of a problem warmly discussed by Sir William Herschel: whether the nebulous masses are subjected to progressive processes of formation, while the cosmical vapour is being condensed around one or more nuclei in accordance with the laws of attraction? By such a condensation of *cosmical vapour*, heat must be liberated, as in every transition of gases and fluids into a state of solidification.[30] If, in accordance with the most recent views, and the important observations of Lord Rosse and Mr. Bond, we may assume that all nebulæ, including those which the highest power of optical instruments has hitherto failed in resolving, are closely crowded stellar swarms, our faith in this perpetually augmenting liberation of heat must necessarily be in some degree weakened. But even small consolidated cosmical bodies which appear on the field of the telescope as distinguishable, luminous points, may change their density by combining in larger masses; and many phenomena presented by our own planetary system lead to the conclusion, that planets have been solidified from a state of vapour, and that their internal heat owes its origin to the formative process of conglomerated matter.

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[29] See Poisson, *Théorie Mathém. de la Chaleur*, p. 438. According to him, the consolidation of the earth's strata began from the centre, and advanced gradually towards the surface; § 193, p. 429. Compare also *Cosmos*, vol. i. p. 169.

[30] *Cosmos*, vol. i. pp. 67, 134.

It may at first sight seem hazardous to term the fearfully low temperature of the regions of space (which varies between the freezing point of mercury and that of spirits of wine) even indirectly *beneficial* to the habitable climates of the earth and to animal and vegetable life. But in proof of the accuracy of the expression, we need only refer to the action of the radiation of heat. The sun-warmed surface of our planet, as well as the atmosphere to its outermost strata, freely radiate heat into space. The loss of heat which they experience arises from the difference of temperature between the vault of heaven and the atmospheric strata, and from the feebleness of the counter-radiation. How enormous would be this loss of heat,[31] if the regions of space, instead of the temperature they now possess, and which we designate as — 76° of a mercury thermometer, had a temperature of about — 1400° or even many thousand times lower!

It still remains for us to consider two hypotheses in relation to the existence of a fluid filling the regions of space, of which one,—the less firmly based hypothesis,—refers to the *limited transparency* of the celestial regions; and the other, founded on direct observation and yielding numerical results, is deduced from the regularly shortened periods of revolution of Encke's comet. Olbers in Bremen, and, as Struve has observed, Loys de Cheseaux at Geneva, eighty years earlier[32] drew attention to the dilemma, that since we could not conceive any point in the infinite regions of space unoccupied by a fixed star, *i. e.* a sun, the entire vault of heaven must appear as luminous as our sun if light were transmitted to us in perfect intensity; or, if such be not the case, we must assume that light experiences a diminution of intensity in its passage through space, this diminution being more excessive than in the inverse ratio of the square of the distance. As we do not observe the whole heavens to be almost uniformly illumined by such a radiance of light (a subject considered by Halley[33] in an hypothesis which he subsequently rejected) the regions of space cannot, according to Cheseaux, Olbers, and Struve, possess perfect and absolute transparency. The results obtained by Sir William Herschel from gauging the stars,[34] and from his ingenious experiments on the space-penetrating power of his great telescopes, seem to show, that if the light of Sirius in its passage to us through a gaseous or ethereal fluid loses only $\frac{1}{800}$th of its intensity, this assumption, which gives the amount of the density of a fluid capable of diminishing light, would suffice to explain the phenomena as they manifest themselves. Among the doubts advanced by the celebrated author of "The New Outlines of Astronomy," against the views of Olbers and Struve, one of the most important is that his twenty-feet telescope shows, throughout the greater portion of the Milky Way in both hemispheres, the smallest stars projected on a black ground.[35]

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[31] "Were there no atmosphere, a thermometer freely exposed (at sunset) to the heating influence of the earth's radiation, and the cooling power of its own into space, would indicate a medium temperature between that of the celestial spaces, (— 132° Fahr.) and that of the earth's surface below it, 82° Fahr., at the equator, 3½° Fahr., in the Polar Sea. Under the equator then it would stand, on the average, at — 25° Fahr., and in the Polar Sea at — 68° Fahr. The presence of the atmosphere tends to prevent the thermometer so exposed from attaining these extreme low temperatures: first, by imparting heat by conduction; secondly, by impeding radiation outwards." Sir John Herschel, in the *Edinburgh Review*, vol. 87, 1848, p. 222. "Si la chaleur des espaces planétaires n'existait point, notre atmosphère éprouverait un refroidissement, dont on ne peut fixer la limite. Probablement la vie des plantes et des animaux serait impossible à la surface du globe, ou reléguée dans une étroite zone de cette surface." (Saigey, *Physique du Globe*, p. 77.)

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[32] *Traité de la Comète de* 1743, *avec une Addition sur la force de la Lumière et sa Propagation dans l'éther, et sur la distance des étoiles fixes;* par Loys de Cheseaux (1744). On the transparency of the regions of space, see Olbers, in *Bode's Jahrbuch für* 1826, s. 110–121; and Struve, *Etudes d'Astr Stellaire*, 1847, pp. 83–93, and note 95. Compare also Sir John Herschel, *Outlines of Astronomy*, § 798, and *Cosmos*, vol. i. p. 142.

[33] Halley, *On the Infinity of the Sphere of Fixed Stars*, in the *Philos. Transact.*, vol. xxxi. for the year 1720, pp. 22–26.

[34] *Cosmos*, vol. i. p. 70.

A better proof, and one based, as we have already stated, upon direct observation of the existence of a resisting fluid,[36] is afforded by Encke's comet, and by the ingenious and important conclusion to which my friend was led in his observations on this body. This resisting medium, must, however, be regarded as different from the all-penetrating light-ether, because the former is only capable of offering resistance inasmuch as it cannot penetrate through solid matter. These observations require the assumption of a tangential force to explain the diminished period of revolution (the diminished major-axis of the ellipse), and this is most directly afforded by the hypothesis of a resisting fluid.[37] The greatest action is manifested during the twenty-five days immediately preceding and succeeding the comet's perihelion passage. The value of the constant is therefore somewhat different, because in the neighbourhood of the sun the highly attenuated, but still gravitating strata of the resisting fluid, are denser. Olbers maintained[38] that this fluid could not be at rest, but must rotate directly round the sun; and therefore the resistance offered to retrograde comets, like Halley's, must differ wholly from that opposed to those comets having a direct course, like Encke's. The perturbations of comets having long periods of revolution, and the difference of their magnitudes and sizes, complicate the results, and render it difficult to determine what is ascribable to individual forces.

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[35] "Throughout by far the larger portion of the extent of the Milky Way in both hemispheres, the *general blackness* of the ground of the heavens, on which its stars are projected . . . . In those regions where the zone is clearly resolved into stars, well separated, and seen projected *on a black ground*, and where we look out beyond them into space. . . . ." Sir John Herschel, *Outlines of Astr.*, pp. 537, 539.

[36] *Cosmos*, vol. i. pp. 69, 70, 92; compare also Laplace, *Essai Philosophique sur les Probabilités*, 1825, p. 133; Arago in the *Annuaire du Bureau des Long. pour* 1832, p. 188, pour 1836, p. 216; and Sir John Herschel, *Outlines of Astr.*, § 577.

[37] The oscillatory movement of the emanations from the head of some comets, as in that of 1744, and in Halley's as

The gaseous matter constituting the belt of the Zodiacal light may, as Sir John Herschel[39] expresses it, be merely the denser portion of this comet-resisting medium. Although it may be shown that all nebulæ are crowded stellar masses, indistinctly visible, it is certain that innumerable comets fill the regions of space with matter through the evaporation of their tails, some of which have a length of 56000000 of miles.

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observed by Bessel, between the 12th and 22nd of October, 1835, (Schumacher *Astron. Nachr.*, nos. 300, 302, § 185, 232), "may, indeed, in the case of some individuals of this class of cosmical bodies, exert an influence on the translatory and rotatory motion, and lead us to infer the action of polar forces (§ 201, 229,) which differ from the ordinary attracting force of the sun;" but the regular acceleration observable for sixty-three years in Encke's comet, (whose period of revolution is $3\frac{1}{3}$ years), cannot be regarded as the result of incidental emanations. Compare on this cosmically important subject, Bessel in Schum. *Astron. Nachr.*, no. 289, s. 6, and no. 310, s. 345–350, with Encke's Treatise on the hypothesis of the resisting medium, in Schum., no. 305, s. 265–274.

[38] Olbers in Schum. *Astr. Nachr.*. no. 268, s. 58.

[39] *Outlines of Astronomy*, § 556, 597.

Arago has ingeniously shown, on optical grounds,[40] that the variable stars which always exhibit white light without any change of colour in their periodical phases, might afford a means of determining the superior limit of the density to be assumed for cosmical ether, if we suppose it to be equal to gaseous terrestrial fluids in its power of refraction.

The question of the existence of an ethereal fluid filling the regions of space is closely connected with one warmly agitated by Wollaston,[41] in reference to the definite limit of the atmosphere,—a limit which must necessarily exist at the elevation where the specific elasticity of the air is equipoised by the force of gravity. Faraday's ingenious experiments on the limits of an atmosphere of mercury (that is, the elevation at which mercurial vapours precipitated on gold-leaf cease perceptibly to rise in an air-filled space) have given considerable weight to the assumption of a definite surface of the atmosphere "similar to the surface of the sea." Can any gaseous particles belonging to the region of space blend with our atmosphere and produce meteorological changes? Newton[42] inclined to the idea that such might be the case. If we regard falling stars and meteoric stones as planetary asteroids, we may be allowed to conjecture that in the streams of the so-called November phenomena,[43] when, as in 1799, 1833 and 1834, myriads of falling stars traversed the vault of heaven, and *northern lights* were simultaneously observed, our atmosphere may have received from the regions of space some elements foreign to it, which were capable of exciting electro-magnetic processes.

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[40] "*En assimilant la matière très rare qui remplit les espaces célestes quant à ses propriétés réfringentes aux gas terrestres, la densité de cette matière ne saurait dépasser une certaine limite dont les observations des étoiles changeantes, p. e. celles d'Algol ou de β de Persée, peuvent assigner la valeur.*" Arago in the *Annuaire pour* 1842, pp. 336–345. "On comparing the extremely rare matter occupying the regions of space with terrestrial gases, in respect to its refractive properties, we shall find that the density of this matter cannot exceed a definite limit, whose value may be obtained from observations of variable stars, as, for instance, Algol or β Persei."

[41] See Wollaston, *Philos. Transact.* for 1822, p. 89; Sir John Herschel, *op. cit.* § 34, 36.

[42] Newton, *Princ. Mathem.*, t. iii. (1760) p. 671. "Vapores

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qui ex sole et stellis fixis et *caudis cometarum* oriuntur, incidere *possunt* in atmosphæras planetarum. . . . . ."

[43] *Cosmos*, vol. i. pp. 112, 124.

## II.

## NATURAL AND TELESCOPIC VISION.—SCINTILLATION OF THE STARS.—VELOCITY OF LIGHT.—RESULTS OF PHOTOMETRY.

THE increased power of vision yielded nearly two hundred and fifty years ago by the invention of the telescope, has afforded to the eye, as the organ of sensuous cosmical contemplation, the noblest of all aids towards a knowledge of the contents of space, and the investigation of the configuration, physical character, and masses of the planets and their satellites. The first telescope was constructed in 1608, seven years after the death of the great observer, Tycho Brahe. Its earliest fruits were the successive discovery of the satellites of Jupiter, the Sun's spots, the crescent-shape of Venus, the ring of Saturn as a triple planetary formation, (planeta tergeminus,) telescopic stellar swarms, and the nebulæ in Andromeda.[1] In 1634, the French astronomer, Morin, eminent for his observations on longitude, first conceived the idea of mounting a telescope on the index bar of an instrument of measurement, and seeking to discover Arcturus by day.[2] The perfection in the graduation of the arc would have failed entirely, or to a considerable extent, in affording that greater precision of observation at which it aimed, if optical and astronomical instruments had not been brought into accord, and the correctness of vision made to correspond with that of measurement. The micrometer-application of fine threads stretched in the focus of the telescope, to which that instrument owes its real and invaluable importance, was first devised, six years afterwards (1640), by the young and talented Gascoigne.[3]

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[1] See *Cosmos*, vol. ii. pp. 699–718, with notes.

[2] Delambre, *Histoire de l'Astronomie moderne*, tom. ii. pp. 255, 269, 272. Morin, in his work, *Scientia Longitudinum*, which appeared in 1634, writes as follows:—*Applicatio tubi optici ad alhidadam pro stellis fixis prompte et accurate mensurandis a me excogitata est.* Picard had not, up to the year 1667, employed any telescope on the mural circle; and Hevelius, when Halley visited him at Dantzic in 1679, and admired the precision of his measurement of altitudes, was observing through improved slits or openings. (Baily's *Catal. of Stars*, p. 38.)

While, as I have already observed, telescopic vision, observation, and measurement, extend only over a period of about 240 years in the history of astronomical science, we find, without including the epoch of the Chaldeans, Egyptians, and Chinese, that more than nineteen centuries have intervened between the age of Timochares and Aristillus[4] and the discoveries of Galileo, during which period the position and course of the stars were observed by the eye alone, unaided by instruments. When we consider the numerous disturbances which during this prolonged period checked the advance of civilization, and the extension of the sphere of ideas among the nations inhabiting the basin of the Mediterranean, we are astonished that Hipparchus and Ptolemy should have been so well acquainted with the precession of the equinoxes, the complicated movements of the planets, the two principal inequalities of the moon, and the position of the stars; that Copernicus should have had so great a knowledge of the true system of the universe; and that Tycho Brahe should have been so familiar with the methods of practical astronomy before the discovery of the telescope. Long tubes, which were certainly employed by Arabian astronomers, and very probably also by the Greeks and Romans, may indeed, in some degree, have increased the exactness of the observations by causing the object to be seen through diopters or slits. Abul-Hassan speaks very distinctly of tubes, to the extremities of which ocular and object diopters were attached; and instruments so constructed were used in the observatory founded by Hulagu at Meragha. If stars be more easily discovered during twilight by means of tubes, and if a star be sooner revealed to the naked eye through a tube than without it, the reason lies, as Arago has already observed, in the circumstance that the tube conceals a great portion of the disturbing light (*rayons perturbateurs*) diffused in the atmospheric strata between the star and the eye applied to the tube. In like manner, the tube prevents the lateral impression of the faint light which the particles of air receive at night from all the other stars in the firmament. The intensity of the image and the size of the star are apparently augmented. In a frequently emendated and much contested passage of Strabo, in which mention is made of looking through tubes, this "enlarged form of the stars" is expressly mentioned, and is erroneously ascribed to refraction.[6]

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[3] The unfortunate Gascoigne, whose merits remained so long unacknowledged, lost his life, when scarcely twenty-three years of age, at the battle of Marston-Moor, fought by Cromwell against the royalists. See Derham in the *Philos. Transact.*, vol. xxx. for 1717–1719, pp. 603–610. To him belongs the merit of a discovery which was long ascribed to Picard and Auzout, and which has given an impulse previously unknown to practical astronomy, the principal object of which is to determine positions in the vault of heaven.

[4] *Cosmos*, vol. ii. p. 544.

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[6] The passage in which Strabo (lib. iii. p. 138, Casaub.) attempts to refute the views of Posidonius is given as follows, according to the manuscripts:—"The image of the sun is enlarged on the seas at its rising as well as at its setting, because at these times a larger mass of exhalations rises from the humid element; and the eye, looking through these exhalations, sees images refracted into larger forms, as observed *through tubes*. The same thing happens when the setting

Light, from whatever source it comes,—whether from the sun, as solar light, or reflected from the planets; from the fixed stars; from putrescent wood; or as the product of the vital activity of glow-worms,—always exhibits the same con-

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sun or moon is seen through a dry and thin cloud, when those bodies likewise appear reddish." This passage has recently been pronounced corrupt (see Kramer, in *Strabonis Geogr.* 1844, vol. i. p. 211), and δὶ ὑάλων (through glass spheres) substituted for δὶ αὐλῶν (Schneider, *Eclog. phys.*, vol. ii. p. 273). The magnifying power of hollow glass spheres, filled with water (Seneca, i, 6), was, indeed, as familiar to the ancients as the action of burning glasses or crystals (Aristoph. *Nub.*, v. 765), and that of Nero's emerald (Plin., xxxvii. 5); but these spheres most assuredly could not have been employed as astronomical measuring instruments. (Compare *Cosmos*, vol. i. p. 619, and note ‡.) Solar altitudes, taken through thin light clouds, or through volcanic vapours, exhibit no trace of the influence of refraction. (Humboldt, *Recueil d'Observ. astr.*, vol. i. p. 123.) Colonel Baeyer observed no angular deviation in the heliotrope light on the passage of streaks of mist, or even from artificially developed vapours, and therefore fully confirms Arago's experiments. Peters, at Pulkowa, in no case found a difference of 0″·017 on comparing groups of stellar altitudes, measured in a clear sky, and through light clouds. See his *Recherches sur la Parallaxe des Etoiles*, 1848, pp. 80, 140–143; also Struve's *Etudes Stellaires*, p. 98. On the application of tubes for astronomical observation in Arabian instruments, see Jourdain, *Sur l'Observatoire de Meragha*, p. 27; and A. Sédillot, *Mém. sur les Instruments astronomiques des Arabes*, 1841, p. 198. Arabian astronomers have also the merit of having first employed large *gnomons* with small circular apertures. In the colossal sextant of Abu Mohammed al-Chokandi, the limb, which was divided into intervals of five minutes, received the image of the sun. " A midi les rayons du soleil passaient par une ouverture pratique dans la voûte de l'observatoire qui couvrait l'instrument, suivant le tuyau, et formaient sur la concavité du sextant une image circulaire, dont le centre donnait, sur l'arc gradué, le complement de la hauteur du soleil. Cet instruditions of refraction.[6] But the prismatic spectra yielded by different sources of light (as the sun and the fixed stars) exhibit a difference in the position of the dark lines (*raies du spectre*) which Wollaston first discovered in 1808, and the position of which was twelve years afterwards so accurately determined by Fraunhofer. While the latter observer counted 600 dark lines (breaks or interruptions in the coloured spectrum), Sir David Brewster, by his admirable experiments with nitric oxide, succeeded, in 1833, in counting more than 2000 lines. It had been remarked that certain lines failed in the spectrum at some seasons of the year; but Sir David Brewster

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ment differe de notre mural, qu'en ce qu'il etait garni d'un simple tuyau au lieu d'une lunette." "At noon, the rays of the sun passed through an opening in the dome of the observatory, above the instrument, and following the tube formed in the concavity of the sextant a circular image, the centre of which marked the sun's altitude on the graduated limb. This instrument in no way differed from our mural circle, excepting that it was furnished with a mere tube instead of a telescope." Sédillot, pp. 37, 202, 205. Dioptric rulers (*pinnulæ*) were used by the Greeks and Arabs in determining the moon's diameter, and were constructed in such a manner, that the circular aperture in the moving object diopter was larger than that of the fixed ocular diopter, and was drawn out until the lunar disc, seen through the ocular aperture, completely filled the object aperture. Delambre, *Hist. de l'Astron. du moyen age*, p. 201; and Sédillot, p. 198. The adjustment of the dioptric rulers of Archimedes, with round apertures or slits, in which the direction of the shadows of two small cylinders attached to the same index bar was noted, seems to have been originally introduced by Hipparchus. (Baily, *Hist. de l'Astron. mod.*, 2nd ed. 1785, tom. i. p. 480.) Compare also, Theon Alexandrin., Bas., 1538, pp. 257, 262; *Les Hypotyp. de Proclus Diadochus* ed. Halma, 1820, pp. 107, 110; and *Ptolem. Almag.*, ed. Halma, tom. i. Par. 1813, p. lvii.

[6] According to Arago; see Moigno, *Répert. d'Optique moderne*, 1847, p. 153.

has shown that this phenomenon is owing to different altitudes of the sun, and to the different absorption of the rays of light in their passage through the atmosphere. In the spectra of the light reflected from the moon, from Venus, Mars, and the clouds, we recognize, as might be anticipated, all the peculiarities of the solar spectrum; but on the other hand, the dark lines in the spectrum of Sirius differ from those of Castor, and the other fixed stars. Castor likewise exhibits different lines from Pollux and Procyon. Amici has confirmed this difference, which was first indicated by Fraunhofer, and has ingeniously called attention to the fact that in fixed stars which now have an equal and perfectly white light the dark lines are not the same. A wide and important field is thus still open to future investigations,[7] for we have yet to distinguish between that which has been determined with certainty, and that which is merely accidental and depending on the absorbing action of the atmospheric strata.

We must here refer to another phenomenon, which is powerfully influenced by the specific character of the source of light. The light of incandescent solid bodies, and the light of the electric spark, exhibit great diversity in the number and position of Wollaston's dark lines. From Wheatstone's remarkable experiments with revolving mirrors it would appear that the light of frictional electricity has a greater velocity than solar light, in the ratio of 3 to 2; that is to say, a velocity of 95908 miles in one second.

The stimulus infused into all departments of optical science by the important discovery of polarisation,[8] to which the ingenious Malus was led in 1808, by a casual observation of the light of the setting sun, reflected from the windows of the Palais du Luxembourg, has afforded unexpected results to science by the more thorough investigation of the phenomena of double refraction, of ordinary (Huygens's) and of chromatic polarisation, of interference, and of diffraction of light. Among these results, may be reckoned the means of distinguishing between direct and reflected light,[9] the power of penetrating, as it were, into the constitution of the body of the sun and of its luminous envelopes,[10] of measuring the pressure of atmospheric strata, and even the smallest amount of water they contain, of scrutinizing the depths of the ocean and its rocks by means of

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[7] On the relation of the dark lines of the solar spectrum in the Daguerreotype, see *Comptes rendus des séances de l'Académie des Sciences*, tom. xiv. 1842, pp. 902–904, and tom. xvi. 1843, pp. 402–407.

[8] *Cosmos*, vol. ii. p. 715.

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[9] Arago's investigation of cometary light may here be adduced as an instance of the important difference between proper and reflected light. The formation of the complementary colours, red and green, showed by the application of his discovery (in 1811) of *chromatic polarisation*, that the light of Halley's Comet (1835) contained *reflected solar light.* I was myself present at the earlier experiments for comparing, by means of the equal and unequal intensity of the images in the polariscope, the proper light of Capella with the splendid Comet, as it suddenly emerged from the rays of the sun at the beginning of July, 1819. (See *Annuaire du Bureau des Long. pour* 1836, p. 232; *Cosmos*, vol. i. p. 90; and Bessel in Schumacher's *Jahrbuch für* 1837, 169.)

[10] *Lettre de M. Arago à M. Alexandre de Humboldt*, 1840, p. 37:—"A l'aide d'un polariscope de mon invention, je reconnus (avant 1820) que la lumière de tous les corps terrestres incandescents, *solides* ou *liquides*, est de la lumière naturelle, tant qu'elle émane du corps sous des incidences perpendiculaires. La lumière, au contraire, qui sort de la surface incandescente sous un angle aigu, offre des marques manifestes de polarisation. Je ne m'arrête pas à te rappeler ici, comment je déduisis de ce fait la conséquence curieuse que la lumière ne s'engendre pas seulement à la surface des corps; qu'une portion naît *dans leur substance même*, cette substance fût-elle du platine. J'ai seulement besoin de dire qu'en répétant la même série d'épreuves, et avec les mêmes instruments sur la lumière que lance une substance *gazeuse* enflammée, on ne lui trouve, *sous quelque inclinaison que ce soit*, aucun des caractères de la *lumière polarisée;* que la lumière des gaz, prise à la

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sortie de la surface enflammée, est de la lumière naturelle, ce qui n'empêche pas qu'elle ne se polarise ensuite complètement si on la soumet à des réflexions ou à des réfractions convenables. De là une méthode très simple pour découvrir à 40 millions de lieues de distance la nature du soleil. La lumière provenant *du bord de cet astre*. la lumière émanée de la matière solaire *sous un angle aigu*, et nous arrivant sans avoir éprouvé en route des réflexions ou des réfractions sensibles, offre-t-elle des traces de polarisation, le soleil est un corps *solide* ou *liquide*. S'il n'y a, au contraire, aucun indice de polarisation dans la lumière du bord, la *partie incandescente* du soleil est *gazeuse*. C'est par cet enchaînement méthodique d'observations qu'on peut arriver à des notions exactes sur la constitution physique du soleil."

"By the aid of my polariscope I discovered (before 1820) that the light of all terrestrial objects in a state of incandescence, whether they be solid or liquid, is natural as long as it emanates from the object in perpendicular rays. The light emanating from an incandescent surface at an acute angle presents on the other hand manifest proofs of polarisation. I will not pause to remind you that this circumstance has led me to the remarkable conclusion that light is not generated on the surface of bodies only, but that some portion is actually engendered within the substance itself, even in the case of platinum. I need only here observe, that in repeating the same series of experiments (and with the same instruments) on the light emanating from a burning gaseous substance, I could not discover any characteristics of *polarised light*, *whatever might be the angle* at which it emanated; and I found that the light of gaseous bodies is natural light when it issues from the burning surface, although this circumstance does not prevent its subsequent complete polarisation, if subjected to suitable reflections or refractions. Hence we obtain a most simple method of discovering the nature of the sun at a distance of 40 millions of leagues. For if the light emanating from the margin of the sun, and radiating from the solar substance *at an acute angle*, reach us without having experienced any sensible reflections or refractions in its passage to the earth, and if it offer traces a tourmaline plate,[11] and, in accordance with Newton's prediction, of comparing the chemical composition[12] of several substances[13] with their optical effects. It will be suffi-

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of polarisation the sun must be a *solid or a liquid body*. But if on the contrary the light emanating from the sun's margin give no indications of polarisation, the *incandescent portion* of the sun must be *gaseous*. It is by means of such a methodical sequence of observations that we may acquire exact ideas regarding the physical constitution of the sun." (On the Envelopes of the Sun, see Arago, in the *Annuaire pour* 1846, p. 464.) I give all the circumstantial optical disquisitions which I have borrowed from the manuscript or printed works of my friend, in his own words, in order to avoid the misconceptions to which the variations of scientific terminology might give rise in re-translating the passages into French, or any other of the various languages in which the *Cosmos* has appeared.

[11] "Sur l'effet d'une lame de tourmaline taillée parallèlement aux arêtes du prisme servant, lorsqu'elle est convenablement située, à éliminer en totalité les rayons réfléchis par la surface de la mer et mêlés à la lumière provenant de l'écueil." "On the effect of a tourmaline plate cut parallel to the edges of the prism, in concentrating (when placed in a suitable position) all the rays of light reflected by the surface of the sea, and blended with the light emanating from the sunken rocks." See Arago, *Instructions de la Bonite*, in the *Annuaire pour* 1836, pp. 339–343.

[12] "De la possibilité de déterminer les pouvoirs réfringents des corps d'après leur composition chimique." On the possibility of determining the refracting powers of bodies according to their chemical composition (applied to the ratio of the oxygen to the nitrogen in atmospheric air, to the quantity of hydrogen contained in ammonia and in water, to carbonic acid, alcohol and the diamond). See *Biot et Arago*, *Mémoire sur les affinités des corps pour la lumière*, Mars, 1806; also *Mémoires mathém. et phys. de l'Institut*, t. vii. pp. 327–346; and my *Mémoire sur les réfractions astronomiques dans la zone torride*, in the *Recueil d'Observ. astron.*, vol. i. pp. 115 and 122.

[13] *Expériences de M. Arago sur la puissance réfractive des corps diaphanes (de l'air sec et de l'air humide) par le déplacement des franges*, in Moigno, *Répertoire d'Optique mod.*, 1847, pp. 159–162.

cient to mention the names of Airy, Arago, Biot, Brewster, Cauchy, Faraday, Fresnel, John Herschel, Lloyd, Malus, Neumann, Plateau, Seebeck, . . . . . to remind the scientific reader of a succession of splendid discoveries, and of their happy applications. The great and intellectual labours of Thomas Young more than prepared the way for these important efforts. Arago's polariscope and the observation of the position of coloured fringes of diffraction (in consequence of interference) have been extensively employed in the prosecution of scientific inquiry. *Meteorology* has made equal advances with *physical astronomy* in this new path.

However diversified the power of vision may be in different persons, there is nevertheless a certain average of organic capacity, which was the same among former generations, as, for instance, the Greeks and Romans, as at the present day. The Pleiades prove that several thousand years ago, even as now, stars which astronomers regard as of the 7th magnitude, were invisible to the naked eye of average visual power. The group of the Pleiades consists of one star of the 3rd magnitude, Alcyone; of two of the 4th, Electra and Atlas; of three of the 5th, Merope, Maïa, and Taygeta; of two between the 6th and the 7th magnitudes, Pleione and Celæno; of one between the 7th and the 8th, Asterope; and of many very minute telescopic stars. I make use of the nomenclature and order of succession at present adopted, as the same names were amongst the ancients in part applied to other stars. The six first-named stars of the 3rd, 4th and 5th magnitudes were the only ones which could be readily distinguished.[14]

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[14] Hipparchus says (*ad Arati Phæn.* 1, pag. 190, in *Uranologio Petavii*), in refutation of the assertion of Aratus, that there were only six stars visible in the Pleiades :—" One star escaped the attention of Aratus. For when the eye is attentively fixed on this constellation on a *serene and moonless night*, seven stars are visible, and it therefore seems strange

Of these Ovid says (*Fast.* IV. 170),

> "Quæ septem dici, sex tamen esse solent."

One of the daughters of Atlas, Merope, the only one who was wedded to a mortal, was said to have veiled herself for very shame, or even to have wholly disappeared. This is probably the star of about the 7th magnitude, which we call Celæno; for Hipparchus, in his commentary on Aratus, observes that on clear moonless nights seven stars may actually be seen. Celæno therefore must have been seen, for Pleione, which is of equal brightness, is too near to Atlas, a star of the 4th magnitude.

The little star, Alcor, which, according to Triesnecker, is situated in the tail of the Great Bear, at a distance of 11′ 48″ from Mizar, is, according to Argelander, of the 5th magnitude, but overpowered by the rays of Mizar. It was called by the Arabs, Saidak, "the Test," because, as the Persian astronomer Kazwini[16] remarks, "It was employed as a test of

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that Attalus, in his description of the Pleiades, should have neglected to notice this oversight on the part of Aratus, as though he regarded the statement as correct." Merope is called the *invisible* (παναφανής) in the *Catasterisms* (XXIII.) ascribed to Eratosthenes. On a supposed connexion between the name of the *veiled* (the daughter of Atlas) with the geographical myths in the *Meropis* of Theopompus, as well as with the great *Saturnian* Continent of Plutarch and the Atlantis, see my *Examen crit. de l'hist. de la Géographie*, t. i. p. 170. Compare also Ideler, *Untersuchungen über den Ursprung und die Bedeutung der Sternnamen*, 1809, p. 145; and in reference to astronomical determination of place, consult Mädler, *Untersuch. über die Fixstern-Systeme*, th. ii. 1848, s. 36 and 166; also Baily in the *Mem. of the Astr. Soc.*, vol. xiii. p. 33.

[15] See Ideler, *Sternnamen*, s. 19 and 25. Arago in manuscript notices of the year 1847, writes as follows.—"On observe qu'une lumière forte fait disparaître une lumière faible placée dans le voisinage. Quelle peut en être la cause? Il est possible physiologiquement que l'ébranlement communiqué à la rétine par la lumière forte s'étend au delà des points que la

the power of vision." Notwithstanding the low position of the Great Bear under the tropics, I have very distinctly seen Alcor, evening after evening, with the naked

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lumière forte a frappés, et que cet ébranlement secondaire absorbe et neutralise en quelque sorte l'ébranlement provenant de la seconde et faible lumière. Mais sans entrer dans ces causes physiologiques, il y a une cause directe qu'on peut indiquer pour la disparition de la faible lumière : c'est que les rayons provenant de la grande n'ont pas seulement formé une image nette sur la rétine, mais se sont dispersés aussi sur toutes les parties de cet organe à cause des imperfections de transparence de la cornée. Les rayons du corps plus brillant *a* en traversant la cornée se comportent comme en traversant un corps legèrement dépoli. Une partie des ces rayons refractés régulièrement forme l'image même de *a*, l'autre partie *dispersée* éclaire la totalité de la rétine. C'est donc sur ce fond lumineux que se projette l'image de l'objet voisin *b*. Cette dernière image doit donc ou disparaître ou être affaiblie. De jour deux causes contribuent à l'affaiblissement des étoiles. L'une de ces causes c'est l'image distincte de cette portion de l'atmosphère comprise dans la direction de l'étoile (de la portion aërienne placée entre l'œil et l'étoile) et sur laquelle l'image de l'étoile vient de se peindre; l'autre cause c'est la lumière diffuse provenant de la dispersion que les défauts de la cornée imprîment aux rayons émanants de tous les points de l'atmosphère visible. *De nuit* les couches atmosphériques interposées entre l'œil et l'étoile vers laquelle on vise, n'agissent pas ; chaque étoile du firmament forme une image plus nette, mais une partie de leur lumière se trouve dispersée à cause du manque de diaphanité de la cornée. Le même raisonnement s'applique à une deuxième, troisième . . . . millième étoile. La rétine se trouve donc éclairée en totalité par une lumière diffuse, proportionnelle au nombre de ces étoiles et à leur éclat. On conçoit par là que cette somme de lumière diffuse affaiblisse ou fasse entièrement disparaître l'image de l'étoile vers laquelle on dirige la vue."

"We find that a strong light causes a fainter one placed near it to disappear. What can be the cause of this phenomenon? It is physiologically possible that the vibration eye, on the rainless shores of Cumana, and on the plateaux of the Cordilleras, which are elevated nearly 13000 feet above the level of the sea, while I have seen it less frequently and less distinctly in Europe and in the dry

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communicated to the retina by strong light may extend beyond the points excited by it; and that this secondary vibration may in some degree absorb and neutralise that arising from the second feeble light. Without, however, entering upon these physiological considerations, there is a direct cause to which we may refer the disappearance of the feeble light: viz., that the rays emanating from the strong light, after forming a perfect image on the retina, are dispersed over all parts of this organ in consequence of the imperfect transparency of the cornea. The rays of the more brilliant body *a*, in passing the cornea, are affected in the same manner as if they were transmitted through a body whose surface was not perfectly smooth. Some of these *regularly refracted* rays form the image *a*, whilst the remainder of the *dispersed* rays illumine the whole of the retina. On this luminous ground the image of the neighbouring object *b* is projected. This last image must therefore either wholly disappear or be dimmed. By day two causes contribute to weaken the light of the stars; one is the distinct image of that portion of the atmosphere included in the direction of the star (the aerial field interposed between the eye and the star), and on which the image of the star is formed, while the other is the light diffused by the dispersion which the defects of the cornea impress on the rays emanating from all points of the visible atmosphere. *At night*, the strata of air interposed between the eye and the star to which we direct the instrument, exert no disturbing action; each star in the firmament forms a more perfect image, but a portion of the light of the stars is dispersed in consequence of the imperfect transparency of the cornea. The same reasoning applies to a second, a third, or a thousandth star. The retina then is entirely illumined by a diffused light, proportionate to the number of the stars and to their brilliancy. Hence we may imagine that the aggregate of this diffused light must either weaken, or entirely obliterate the image of the star towards which the eye is directed."

atmosphere of the Steppes of Northern Asia. The limits within which the naked eye is unable to separate two very contiguous objects in the heavens depend, as Mädler has justly observed, on the relative brilliancy of the stars. The two stars of the 3rd and 4th magnitudes, marked as α Capricorni, which are distant from each other six-and-a-half minutes, can with ease be recognized as separate. Galle thinks that ε and 5 Lyræ, being both stars of the 4th magnitude, may be distinguished in a very clear atmosphere by the naked eye, although situated at a distance of only three-and-a-half minutes from each other.

The preponderating effect of the rays of the neighbouring planet is also the principal cause of Jupiter's satellites remaining invisible to the naked eye; they are not all, however, as has frequently been maintained, equal in brightness to stars of the 5th magnitude. My friend, Dr. Galle, has found from recent estimates, and by a comparison with neighbouring stars, that the third and brightest satellite is probably of the 5th or 6th magnitude, whilst the others, which are of various degrees of brightness, are all of the 6th or 7th magnitude. There are only few cases on record in which persons of extraordinarily acute vision—that is to say, capable of clearly distinguishing with the naked eye stars fainter than those of the 6th magnitude,—have been able to distinguish the satellites of Jupiter without a telescope. The angular distance of the third and brightest satellite from the centre of the planet is 4′ 42″; that of the fourth, which is only $\frac{1}{6}$th smaller than the largest is 8′ 16″: and all Jupiter's satellites sometimes exhibit, as Arago maintains,[16] a more intense light for equal surfaces than Jupiter himself; occasionally, however, as shown by recent observations, they appear like gray spots on the planet. The rays or tails, which to our eyes appear to radiate from the planets and fixed stars, and which were used, since the earliest ages of mankind, and especially amongst the Egyptians,

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[16] Arago, in the *Annuaire pour* 1842, p. 284, and in the *Comptes rendus*, tom. xv. 1842, p. 750. (Schum. *Astron. Nachr.*, no. 702.) "I have instituted some calculations of magnitudes, in reference to your conjectures on the visibility of Jupiter's satellites," writes Dr. Galle, in letters addressed

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to me, "but I have found, contrary to my expectations, that they are not of the 5th magnitude, but, at most, only of the 6th or even of the 7th magnitude. The 3rd and brightest satellite alone appeared nearly equal in brightness to a neighbouring star of the 6th magnitude, which I could scarcely recognize with the naked eye, even at some distance from Jupiter; so that, considered in reference to the brightness of Jupiter, this satellite would probably be of the 5th or 6th magnitude if it were isolated from the planet. The 4th satellite was at its greatest elongation, but yet I could not estimate it at more than the 7th magnitude. The rays of Jupiter would not prevent this satellite from being seen if it were itself brighter. From a comparison of Aldebaran with the neighbouring star θ Tauri, which is easily recognized as a double star (at a distance of 5½ minutes), I should estimate the radiation of Jupiter at five or six minutes, at the least, for ordinary vision." These estimates correspond with those of Arago, who is even of opinion that this false radiation may amount in the case of some persons to double this quantity. The mean distances of the four satellites from the centre of the main planet are undoubtedly 1′51″, 2′57″, 4′42″, and 8′16″. "Si nous supposons que l'image de Jupiter, dans certains yeux exceptionnels, s'épanouisse seulement par des rayons d'une ou deux minutes d'amplitude, il ne semblera pas impossible que les satellites soient de tems en tems aperçus, sans avoir besoin de recourir à l'artifice de l'amplification. Pour vérifier cette conjecture, j'ai fait construire une petite lunette dans laquelle l'objectif et l'oculaire ont a peu près le même foyer, et qui dès lors ne *grossit point*. Cette lunette ne détruit pas entièrement les rayons divergents, mais elle en réduit considèrablement la longueur. Cela a suffi pour qu'un satellite convenablement écarté de la planète, soit devenu visible. Le fait a été constaté par tous les jeunes astronomes de l'Observatoire." "If we suppose that the image of Jupiter appears to the eyes as pictorial representations to indicate the shining orbs of heaven, are at least from five to six minutes in length. (These lines are regarded by Hassenfratz as caustics on the crystalline lens : *intersections des deux caustiques*.)

"The image of the star which we see with the naked eye is magnified by diverging rays, in consequence of which it occupies a larger space on the retina than if it were concen-

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of some persons to be dilated by rays of only one or two minutes, it is not impossible that the satellites may from time to time be seen without the aid of magnifying glasses. In order to verify this conjecture I caused a small instrument to be constructed in which the object-glass and the eye-piece had nearly the same focus, and which therefore did *not magnify*. This instrument does not entirely destroy the diverging rays, although it considerably reduces their length. This method has sufficed to render a satellite visible when at a sufficient distance from the planet. This observation has been confirmed by all the young astronomers at the Observatory." (Arago in the *Comptes rendus*, tom. xv. 1842, p. 751.)

As a remarkable instance of acute vision and of the great sensibility of the retina in some individuals who are able to see Jupiter's satellites with the naked eye, I may instance the case of a master tailor, named Schön, who died at Breslau in 1837, and with reference to whom I have received some interesting communications from the learned and active director of the Breslau Observatory, Von Boguslawski. "After having (since 1820) convinced ourselves, by several rigid tests, that in serene moonless nights Schön was able correctly to indicate the position of several of Jupiter's satellites at the same time, we spoke to him of the emanations and tails which appeared to prevent others from seeing so clearly as he did, when he expressed his astonishment at these obstructing radiations. From the animated discussions between himself and the bystanders regarding the difficulty of seeing the satellites with the naked eye, the conclusion was obvious, that the planet and fixed stars must always appear to Schön like luminous points having no rays. He saw the third satellite the best, and the first very plainly when trated in a single point. The impression on the nerves is weaker. A very dense starry swarm, in which scarcely any of the separate stars belong even to the 7th magnitude, may, on the contrary, be visible to the unaided eye in consequence of the images of the many different stars crossing each other upon the retina, by which every sensible point of its surface is more powerfully excited, as if by one concentrated image."[17]

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it was at the greatest digression, but he never saw the second and the fourth alone. When the air was not in a very favourable condition the satellites appeared to him like faint streaks of light. He never mistook small fixed stars for satellites, probably on account of the scintillating and less constant light of the former. Some years before his death Schön complained to me that his failing eye could no longer distinguish Jupiter's satellites, whose position was only indicated, even in clear weather, by light faint streaks." These circumstances entirely coincide with what has been long known regarding the relative lustre of Jupiter's satellites, for the brightness and quality of the light probably exert a greater influence than mere distance from the main planet on persons of such great perfection and sensibility of vision. Schön never saw the second nor the fourth satellite. The former is the smallest of all; the latter, although the largest after the third and the most remote, is periodically obscured by a dark colour, and is generally the faintest of all the satellites. Of the third and the first which were best and most frequently seen by the naked eye, the former, which is the largest of all, is usually the brightest, and of a very decided yellow colour; the latter occasionally exceeds in the intensity of its clear yellow light the lustre of the third, which is also much larger. (Mädler, *Astr.* 1846, s. 231–234, and 439.) Sturm and Airy, in the *Comptes rendus*, t. xx. pp. 764–6, show how, under proper conditions of refraction in the organ of vision, remote luminous points may appear as light streaks.

[17] "L'image *épanouie* d'une étoile de 7ème grandeur n'ébranle pas suffisamment la rétine: elle n'y fait pas naître une sensation appréciable de lumière. Si l'image *n'était point épanouie* (par des rayons divergents), la sensation

Telescopes, although in a much less degree, unfortunately also give the stars an incorrect and spurious diameter; but accord-

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aurait plus de force, et l'étoile se verrait. La première classe d'étoiles invisibles à l'œil nu ne serait plus alors la septième: pour la trouver, il faudrait peut-être descendre alors jusqu'à la 12ème. Considérons un groupe d'étoiles de 7ème grandeur tellement rapprochées les unes des autres que les intervalles échappent necessairement à l'œil. *Si la vision avait de la netteté*, si l'image de chaque étoile était très petite et bien terminée, l'observateur aperceverait un champ de lumière dont chaque point aurait *l'éclat concentré* d'une étoile de 7ème grandeur. *L'éclat concentré* d'une étoile de 7ème grandeur suffit à la vision à l'œil nu. Le groupe serait donc visible à l'œil nu. Dilatons maintenant sur la rétine l'image de chaque étoile du groupe; remplaçons chaque point de l'ancienne image générale par un petit cercle: ces cercles empiéteront les uns sur les autres, et les divers points de la rétine se trouveront éclairés par de la lumière venant simultanément de plusieurs étoiles. Pour peu qu'on y réfléchisse, il restera évident qu' excepté sur les bords de l'image générale, l'aire lumineuse ainsi éclairée a précisément, à cause de la superposition des cercles, la même intensité que dans le cas où chaque étoile n'éclaire qu'un seul point au fond de l'œil; mais si chacun de ces points reçoit une lumière égale en intensité à la lumière concentrée d'une étoile de 7ème grandeur, il est clair que l'épanouissement des images individuelles des étoiles contigues ne doit pas empêcher la visibilité de l'ensemble. Les instruments telescopiques ont, quoiqu'à un beaucoup moindre degré, le défaut de donner aussi aux étoiles un *diamètre sensible et factice.* Avec ces instruments, comme à l'œil nu, on doit donc apercevoir des groupes, composés d'étoiles inférieures en intensité à celles que les mêmes lunettes ou telescopes feraient apercevoir isolément."

"The expanded image of a star of the 7th magnitude does not cause sufficient vibration of the retina, and does not give rise to an appreciable sensation of light. If the image were not expanded (by divergent rays), the sensation would be stronger and the star discernible. The lowest magnitude at which stars are visible would not therefore be the 7th, but some magnitude as low perhaps as the 12th degree. Let us ing to the splendid investigations of Sir William Herschel,[18] these diameters decrease with the increasing power of the instrument. This distinguished observer estimated that, at the excessive magnifying power of 6500, the apparent diameter of Vega Lyræ still amounted to 0″36. In terrestrial objects the form, no less than the mode, of illumination, determines the magnitude of the smallest angle of vision for the naked

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consider a group of stars of the 7th magnitude so close to one another that the intervals between them necessarily escape the eye. *If the sight were very clear*, and the image of each star small and well defined, the observer would perceive a field of light, each point of which would be equal to the *concentrated brightness* of a star of the 7th magnitude. The concentrated light of a star of the 7th magnitude is sufficient to be seen by the naked eye. The group, therefore, would be visible to the naked eye. Let us now dilate the image of each star of the group on the retina, and substitute a small circle for each point of the former general image; these circles will impinge upon one another, and the different points of the retina will be illumined by light emanating simultaneously from many stars. A slight consideration will show, that, excepting at the margins of the general image, the luminous air has, in consequence of the superposition of the circles, the same degree of intensity as in those cases where each star illumines only one single point of the retina; but if each of these points be illumined by a light equal in intensity to the concentrated light of a star of the 7th magnitude, it is evident that the dilatation of the individual images of contiguous stars cannot prevent the visibility of the whole. Telescopic instruments have the defect, although in a much less degree, of giving the stars a sensible and spurious diameter. We therefore perceive with instruments, no less than with the naked eye, groups of stars, inferior in intensity to those which the same telescopic or natural sight would recognize, if they were isolated." Arago, in the *Annuaire du Bureau des Longitudes pour l'an* 1842, p. 284.

[18] Sir William Herschel, in the *Philos. Transact.* for 1803, vol. 93, p. 225, and for 1805, vol. 94, p. 184. Compare also Arago, in the *Annuaire pour* 1842, pp. 360–374.

eye. Adams very correctly observed that a long and slender staff can be seen at a much greater distance than a square whose sides are equal to the diameter of the staff. A stripe may be distinguished at a greater distance than a spot, even when both are of the same diameter. Arago has made numerous calculations on the influence of form (outline of the object) by means of angular measurement of distant lightning conductors visible from the Paris Observatory. The *minimum* optical visual angle at which terrestrial objects can be recognized by the naked eye has been gradually estimated lower and lower from the time when Robert Hooke fixed it exactly at a full minute, and Tobias Mayer required 34″ to perceive a black speck on white paper, to the period of Leeuwenhoek's experiments with spider's threads, which are visible to ordinary sight at an angle of 4″·7. In the recent and most accurate experiments of Hueck, on the problem of the movement of the crystalline lens, white lines on a black ground were seen at an angle of 1″·2; a spider's thread at 0″·6; and a fine glistening wire at scarcely 0″·2. This problem does not admit generally of a numerical solution, since it entirely depends on the form of the objects, their illumination, their contrast with the back-ground, and on the motion or rest, and the nature of the atmospheric strata in which the observer is placed.

During my visit at a charming country-seat belonging to the Marques de Selvalegre, at Chillo, not far from Quito, where the long extended crests of the volcano of Pichincha lay stretched before me at a horizontal distance, trigonometrically determined at more than 90000 feet, I was much struck by the circumstance that the Indians who were standing near me distinguished the figure of my travelling companion Bonpland (who was engaged in an expedition to the volcano) as a white point moving on the black basaltic sides of the rock, sooner than we could discover him with our telescopes. The white moving image was soon detected with the naked eye both by myself and by my friend the unfortunate son of the Marques, Carlos Montufar, who subsequently perished in the civil war. Bonpland was enveloped in a white cotton mantle, the Poncho of the country; assuming the breadth across the shoulders to vary from three to five feet, according as the mantle clung to the figure or fluttered in the breeze, and judging from the known distance, we found that the angle at which the moving object could be distinctly seen, varied from 7″ to 12″. White objects on a black ground are, according to Hueck's repeated experiments, distinguished at a greater distance than black objects on a white ground. The light was transmitted in serene weather through rarefied strata of air at an elevation 15360 feet above the level of the sea to our station at Chillo, which was itself situated at an elevation of 8575 feet. The ascending distance was 91225 feet, or about $17\frac{1}{3}$ miles. The barometer and thermometer stood at very different heights at both stations, being probably at the upper one about 17·2 inches and 46°·4, while at the lower station they were found, by accurate observation, to be 22·2 inches and 65°·7. Gauss's heliotrope light, which has become so important an element in German trigonometrical measurements, has been seen with the naked eye reflected from the Brocken on Hohenhagen, at a distance of about 227000 feet, or more than 42 miles; being frequently visible at points in which the apparent breadth of a three-inch mirror was only 0″·43.

The *visibility* of distant objects is modified by the absorption of the rays passing from the terrestrial object to the naked eye at unequal distances, and through strata of air more or less rarefied and more or less saturated with moisture; by the degree of intensity of the light diffused by the radiation of the particles of air; and by numerous meteorological processes not yet fully explained. It appears from the old experiments of the accurate observer, Bouguer, that a difference of $\frac{1}{60}$th in the intensity of the light is necessary to render objects visible. To use his own expression, we only *negatively* see mountain-tops from which but little light is radiated, and which stand out from the vault of heaven in the form of dark masses; their visibility is solely owing to the difference in the thickness of the atmospheric strata extending respectively to the object and to the horizon. Strongly illumined objects, such as snow-clad mountains, white chalk cliffs, and conical rocks of pumice-stone, are seen *positively*.

The distance at which high mountain summits may be recognized from the sea is not devoid of interest in relation to practical navigation, where exact astronomical determinations are wanting to indicate the ship's place. I have treated this subject more at length in another work,[19] where I considered the distance at which the Peak of Teneriffe might be seen.

The question whether stars can be seen by daylight with the naked eye through the shafts of mines, and on very high mountains, has been with me a subject of inquiry since my early youth. I was aware that Aristotle had maintained[20] that stars might occasionally be seen from caverns and cisterns, as through tubes. Pliny alludes to the same circumstance, and mentions the stars that have been most distinctly recognized during solar eclipses. While practically engaged in mining operations I was in the habit, during many years, of passing a great portion of the day in mines where I could see the sky through deep shafts, yet I never was able to observe a star; nor did I ever meet with any individual in the Mexican, Peruvian, or Siberian mines, who had heard of stars having been seen by day-light; although in the many latitudes, in both hemispheres, in which I have visited deep mines, a sufficiently large number of stars must have passed the zenith to have afforded a favourable opportunity for their being seen. Considering this negative evidence, I am the more struck by the highly credible testimony of a celebrated optician, who in his youth saw stars by day-light, through the shaft of a chimney.[21]

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[19] Humboldt, *Rélation hist. du Voyage aux Régions équinox.* tom. i. pp. 92–97; and Bouguer, *Traité d'Optique*, pp. 360 and 365. (Compare also Captain Beechey in the *Manual of Scientific Enquiry for the use of the Royal Navy*, 1849, p. 71.)

[20] The passage in Aristotle referred to by Buffon occurs in a work where we should have least expected to find it—*De Generat. Animal.*, v. i. p. 780, Bekker. Literally translated, it runs as follows:—"Keenness of sight is as much the power of seeing far, as of accurately distinguishing the differences presented by the objects viewed. These two properties are not met with in the same individuals. For he who holds his hand over his eyes, or *looks through a tube*, is not on that account more or less able to distinguish

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differences of colour, although he will see objects at a greater distance. Hence it arises that persons *in caverns or cisterns are occasionally enabled to see stars.*" The Grecian 'Ορύγματα, and more especially φρέατα, are, as an eye-witness, Professor Franz, observes, subterranean cisterns or reservoirs which communicate with the light and air by means of a vertical shaft, and widen towards the bottom, like the neck of a bottle. Pliny (lib. ii. cap. 14) says, "Altitudo cogit minores videri stellas; affixas cœlo solis fulgor interdiu non cerni, quum æque ac noctu luceant; idque manifestum fiat *defectu solis et prœaltis puteis.*" Cleomedes (*Cycl. Theor.*, p. 83, Bake) does not speak of stars seen by day, but asserts "that the sun, when observed from deep cisterns, appears larger, on account of the darkness and the damp air."

[21] "We have ourselves heard it stated by a celebrated optician that the earliest circumstance which drew his attention to astronomy, was the regular appearance, at a certain hour, for several successive days, of a considerable star, through the shaft of a chimney." John Herschel, *Outlines of Astr.*, § 61. The chimney-sweepers whom I have questioned agree

Phenomena, whose manifestation depends on the accidental concurrence of favouring circumstances, ought not to be disbelieved on account of their rarity.

The same principle must, I think, be applied to the assertion of the profound investigator, Saussure, that stars have been seen with the naked eye in bright day-light, on the declivity of Mont Blanc, and at an elevation of 12757 feet. "Quelques-uns des guides m'ont assuré avoir vu des étoiles en plein jour; pour *moi* je n'y songeais pas, en sorte que je n'ai point été le témoin de ce phénomène; *mais l'assertion uniforme des guides ne me laisse aucun doute sur la réalité.* Il faut d'ailleurs être entièrement à l'ombre d'une épaisseur considérable, sans quoi l'air trop fortement éclairé fait evanouir la faible clarté des étoiles." "Several of the guides assured me," says this distinguished Alpine inquirer, "that they had seen stars at broad day-light; not having myself been a witness of this phenomenon, I did not pay much attention to it, but the unanimous assertions of the guides left me no doubt of its reality.[22] It is essential, however, that the observer should be placed entirely in the shade, and that he should even have a thick and massive shade above his head, since the stronger light of the air would otherwise disperse the faint image of the stars." These conditions are therefore nearly the same as those presented by the cisterns of the ancients, and the chimneys above referred to. I do not find this remarkable statement (made on the morning of the 2nd of August, 1787,) in any other description of the Swiss mountains. Two well-informed,

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tolerably well in the statement that "they have never seen stars by day, but that, when observed at night, through deep shafts, the sky appeared quite near, and the stars larger." I will not enter upon any discussion regarding the connection between these two illusions.

[22] Consult Saussure, *Voyage dans les Alpes*, (Neuchatel, 1779, 4to.) tom. iv. § 2007, p. 199.

admirable observers, the brothers Hermann and Adolph Schlagentweit, who have recently explored the eastern Alps, as far as the summit of the Gross Glockner, (13016 feet,) were never able to see stars by daylight, nor could they hear any report of such a phenomenon having been observed amongst the goatherds and chamois hunters. Although I passed many years in the Cordilleras of Mexico, Quito, and Peru, and frequently in clear weather ascended, in company with Bonpland, to elevations of more than fifteen or sixteen thousand feet above the level of the sea, I never could distinguish stars by day-light, nor was my friend Boussingault more successful in his subsequent expeditions; yet the heavens were of an azure so intensely deep, that a cyanometer (made by Paul of Geneva,) which had stood at 39° when observed by Saussure on Mont Blanc, indicated 46° in the zenith under the tropics at elevations varying between 17000 and 19000 feet.[23] Under the serene etherially-pure sky of Cumana, in the plains near the sea-shore, I have frequently been able, after observing an eclipse of Jupiter's satellites, to find the planet again with the naked eye, and have most distinctly seen it when the sun's disc was from 18° to 20° above the horizon.

The present would seem a fitting place to notice, although cursorily, another optical phenomenon, which I only observed once during my numerous mountain ascents. Before sunrise, on the 22nd of June, 1799, when at Malpays, on the declivity of the Peak of Teneriffe, at an elevation of about 11400 feet above the sea's level, I observed, with the naked eye, stars near the horizon flickering with a singular oscillating motion. Luminous points ascended, moved *laterally*, and fell back to their former position. This phenomenon lasted only from seven to eight minutes, and ceased long before the sun's disc appeared above the horizon of the sea. The same motion was discernible through a telescope, and there was no doubt that it was the stars themselves which moved.[24] Did this change of position depend on the much contested phenomenon of *lateral* radiation? Does the undulation of the rising sun's disc, however inconsiderable it may appear when measured, present any analogy to this phenomenon in the lateral alteration of the sun's margin? Independently of such a consideration, this motion seems greater near the horizon. This phenomenon of the *undulation of the stars* was observed almost half a century later at the same spot by a well-informed and observing traveller, Prince Adalbert, of Prussia, who saw it both with the naked eye and through a telescope. I found the observation recorded in the Prince's manuscript journal, where he had noted it down, before he learned, on his return from the Amazon, that I had witnessed a precisely similar phenomenon.[25]

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[23] Humboldt, *Essai sur la Géographie des Plantes*, p. 103. Compare also my *Voy. aux Régions équinox.*, tom. i. pp. 143, 248

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[24] Humboldt, in Fr. Von Zach's *Monatliche Correspondenz zur Erd-und Himmels-Kunde*, bd. i. 1800, s. 396; also *Voy. aux Rég. équin.*, tom. i. p. 125.—"On croyait voir de petites fusées lancées dans l'air. Des points lumineux élevés de 7 à 8 degrés, paraissent d'abord se mouvoir dans le sens vertical, mais puis se convertir en une véritable oscillation horizontale. Ces images lumineux étaient des images de plusieurs étoiles agrandies (en apparence) par des vapeurs et revenant au même point d'ou elles étaient partis." "It seemed as if a number of small rockets were being projected in the air; luminous points, at an elevation of 7° or 8°, appeared moving, first in a vertical, and then oscillating in a horizontal direction. These were the images of many stars, apparently magnified by vapours, and returning to the same point from which they had emanated."

[25] Prince Adalbert of Prussia, *Aus meinem Tagebuche*, 1847, s. 213. Is the phenomenon I have described connected with the oscillations of 10″–12″, observed by Carlini, in the passage of the Polar star over the field of the great Milan meridian telescope? (See Zach's *Correspondance astrono-*

I was never able to detect any trace of *lateral refraction* on the declivities of the Andes, or during the frequent *mirages* in the torrid plains or *Llanos* of South America, notwithstanding the heterogeneous mixture of unequally heated atmospheric strata. As the Peak of Teneriffe is so near us, and is so frequently ascended before sun-rise by scientific travellers provided with instruments, I would hope that this reiterated invitation on my part to the observation of the *undulation of the stars* may not be wholly disregarded.

I have already called attention to the fact that the basis of a very important part of the astronomy of our planetary system was already laid *before* the memorable years 1608 and 1610, and therefore *before* the great epoch of the invention of telescopic vision, and its application to astronomical purposes. The treasure transmitted by the learning of the Greeks and Arabs, was augmented by the careful and persevering labours of George Purbach, Regiomontanus (*i. e.* Johann Müller) and Bernhard Walther of Nürnberg. To their efforts succeeded a bold and glorious development of thought—the Copernican system; this again was followed by the rich treasures derived from the exact observations of Tycho Brahe, and the combined acumen and persevering spirit of calculation of Kepler. Two great men, Kepler and Galileo, occupy the most important turning-point in the history of measuring astronomy; both indicating the epoch that separates observation by the naked eye, though aided by greatly improved instruments of measurement, from *telescopic vision.* Galileo was at that period forty-four, and Kepler thirty-seven years of age; Tycho

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*mique et géog.*, vol. ii. 1819, p. 84.) Brandes (Gehler's *Umgearb. phys. Wörtersb*, bd. iv s. 549) refers the phenomenon to *mirage.* The star-like heliotrope light has also frequently been seen, by the admirable and skilful observer, Colonel Baeyer, to oscillate to and fro, in a horizontal direction.

Brahe, the most exact of the measuring astronomers of that great age, had been dead seven years. I have already mentioned, in a preceding volume of this work (see p. 711), that none of Kepler's contemporaries, Galileo not excepted, bestowed any adequate praise on the discovery of the three laws which have immortalised his name. Discovered by purely empirical methods, although more rich in results to the whole domain of science, than the isolated discovery of unseen cosmical bodies, these laws belong entirely to the period of *natural vision*, to the epoch of Tycho Brahe and his observations; although the printing of the work entitled *Astronomia nova seu Physica cœlestis de motibus Stellæ Martis*, was not completed until 1609, and the third law, that the squares of the periodic times of revolution of two planets are as the cubes of their mean distances, was first fully developed in 1619, in the *Harmonice Mundi.*

The transition from natural to telescopic vision which characterizes the first ten years of the seventeenth century, was more important to astronomy (the knowledge of the regions of space), than the year 1492, (that of the discoveries of Columbus) in respect to our knowledge of terrestrial space. It not only infinitely extended our insight into creation, but also, besides enriching the sphere of human ideas, raised mathematical science to a previously unattained splendour, by the exposition of new and complicated problems. Thus the increased power of the organs of perception re-acts on the world of thought, to the strengthening of intellectual force, and the ennoblement of humanity. To the telescope alone we owe the discovery, in less than two-and-a-half centuries, of thirteen new planets, of four satellite-systems, (the four moons of Jupiter, eight satellites of Saturn, four, or perhaps six of Uranus, and one of Neptune), of the sun's spots and faculæ, the phases of Venus, the form and height of the lunar mountains, the wintry polar zones of Mars, the belts of Jupiter and Saturn, the rings of the latter, the interior planetary comets of short periods of revolution, together with many other phenomena which likewise escape the naked eye. While our own solar system, which so long seemed limited to six planets and one moon, has been enriched in the space of 240 years with the discoveries to which we have alluded; our knowledge regarding successive strata of the region of the fixed stars has unexpectedly been still more increased. Thousands of nebulæ, stellar swarms, and double stars, have been observed. The changing position of the double stars which revolve round one common centre of gravity has proved, like the proper motion of all fixed stars, that forces of gravitation are operating in those distant regions of space, as in our own limited mutually-disturbing planetary spheres. Since Morin and Gascoigne (not indeed till twenty-five or thirty years after the invention of the telescope,) combined optical arrangements with measuring instruments, we have been enabled to obtain more accurate observations of the change of position of the stars. By this means we are enabled to calculate, with the greatest precision, every change in the position of the planetary bodies, the ellipses of aberration of the fixed stars and their parallaxes, and to measure the relative distances of the double stars even when amounting to only a few tenths of a seconds-arc. The astronomical knowledge of the solar system has gradually extended to that of a system of the universe.

We know that Galileo made his discoveries of Jupiter's satellites with an instrument that magnified only seven diameters, and that he never could have used one of a higher power than thirty-two. One hundred and seventy years later, we find Sir William Herschel, in his investigations on the magnitude of the apparent diameters of Arcturus (0″·2 within the nebula) and of Vega Lyræ, using a power of 6500. Since the middle of the seventeenth century, constant attempts have been made to increase the focal length of the telescope.

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Christian Huygens, indeed, in 1655, discovered the first satellite of Saturn, Titan (the sixth in distance from the centre of the planet), with a twelve-feet telescope; he subsequently however examined the heavens with instruments of a greater focal length, even of 122 feet; but the three object-glasses in the possession of the Royal Society of London whose focal lengths are respectively 123, 170, and 210 feet, and which were constructed by Constantine Huygens, brother of the great astronomer, were only tested by the latter, as he expressly states,[26] upon terrestrial objects. Auzout, who in 1663 constructed colossal telescopes without tubes, and therefore without a solid connexion between the object-glass and the eye-piece, completed an object glass, which, with a focal length of 320 feet, magnified 600 times.[27] The most useful application of these object-glasses, mounted on poles, was that which led Dominic Cassini, between the years 1671 and 1684, to the successive discoveries of the eighth, fifth, fourth, and third satellites of Saturn. He made use of object-glasses that had been ground by Borelli, Campani, and Hartsoeker. Those of the latter had a focal length of 266 feet.

During the many years I passed at the Paris Observatory, I frequently had in my hands the instruments made by Campani, which were in such great repute during the reign of Louis XIV; and when we consider the faint light of Saturn's satellites, and the difficulty of managing instruments, worked by strings only,[28] we cannot sufficiently admire the skill and the untiring perseverance of the observer.

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[26] The remarkable artistical skill of Constantin Huygens, who was private secretary to King William the Third, has only recently been presented in its proper light by Uytenbrock in the "Oratio de fratribus Christiano atque Constantino Hugenio, artis dioptricæ cultoribus," 1838; and by Prof. Kaiser, the learned director of the Observatory at Leyden (in Schumacher's *Astron. Nachr.*, no. 592, s. 246).

[27] See Arago, in the *Annuaire pour* 1844, p. 381.

The advantages which were at that period supposed to be obtainable only by gigantic length, led great minds, as is frequently the case, to extravagant expectations. Auzout considered it necessary to refute Hooke, who is said to have proposed the use of telescopes having a length of upwards of 10000 feet, (or nearly two miles,)[29] in order to see animals in the moon. A sense of the practical inconvenience of optical instruments having a focal length of more than a hundred feet, led, through the influence of Newton, (in following out the earlier attempts of Mersenne and James Gregory of Aberdeen,) to the adoption, especially in England, of shorter reflecting telescopes. The careful comparison made by Bradley and Pond, of Hadley's five-feet reflecting telescopes, with the refractor constructed by Constantin Huygens, (which had, as already observed, a focal length of 123 feet,) fully demonstrated the superiority of the former. Short's expensive reflectors were now generally employed until 1759, when John Dollond's successful practical solution of the problem of achromatism, to which he had been incited by Leonhard Euler, and Klingenstierna, again gave preponderance to refracting instruments. The right of priority which appears to have incontestably belonged to the mysterious Chester More, Esq., of More Hall in Essex, (1729,) was first made known to the public, when John Dollond obtained a patent for his achromatic telescopes.[30]

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[28] "Nous avons placé ces grands verres, tantôt sur un grand mât, tantôt sur la tour de bois venue de Marly; enfin nous les avons mis dans un tuyau monté sur un support en forme d'échelle à trois faces, ce qui a eu (dans la découverte des satellites de Saturne) le succès que nous en avions espéré." "We sometimes mounted these great instruments on a high pole," says Dominique Cassini, "and sometimes on the wooden tower that had been brought from Marly; and we also placed them in a tube mounted on a three-sided ladder, a method which, in the discovery of the satellites of Saturn, gave us all the success we had hoped." Delambre, *Hist. de l'Astr. moderne*, tom. ii. p. 785. Optical instruments having such enormous focal lengths remind us of the Arabian instruments of measurement—quadrants with a radius of about 190 feet, upon whose graduated limb the image of the sun was received as in the gnomon, through a small round aperture. Such a quadrant was erected at Samarcand, probably constructed after the model of the older sextants of Al-Chokandi (which were about 60 feet in height). Compare Sédillot, *Prolégomènes des Tables d'Oloug. Beigh*, 1847, p. lvii. and cxxix.

[29] See Delambre, *Hist. de l'Astr. mod.*, t. ii. p. 594. The mystic Capuchin Monk, Schyrle von Rheita, who however was well versed in optics, had already spoken in his work, *Oculus Enoch et Eliæ*, (Antv. 1645) of the speedy practicability of constructing telescopes that should magnify 4000 times, by means of which the lunar mountains might be accurately laid down. Compare also *Cosmos*, vol. ii. p. 705 (note).

The triumph obtained by refracting instruments was not, however, of long duration. In eighteen or twenty years after the construction of achromatic instruments by John Dollond, by the combination of crown with flint glass, new fluctuations of opinion were excited by the just admiration awarded, both at home and abroad, to the immortal labours of a German, William Herschel. The construction of numerous seven-feet and twenty-feet telescopes, to which powers of from 2200 to 6000 could be applied, was followed by that of his forty-feet reflector. By this instrument he discovered, in August and September, 1789, the two innermost satellites of Saturn—Enceladus, the second in order, and soon afterwards, Mimas, the first or the one nearest to the ring. The discovery of the planet Uranus in 1781, was made with Herschel's seven-feet telescope, while the faint satellites of this planet were first observed by him in 1787, with a twenty-feet "*fron. view*" reflector.[31] The perfection, unattained till then, which this great man gave to his reflecting telescopes, in which light was only once reflected, led, by the uninterrupted labour of more than forty years, to the most important extension of all departments of physical astronomy in the planetary spheres, no less than in the world of nebulæ and double stars.

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[30] *Edinb. Encyclopedia*, vol. xx. p. 479

The long predominance of reflectors was followed, in the earlier part of the nineteenth century, by a successful emulation in the construction of achromatic *refractors*, and *heliometers*, paralactically moved by clockwork. A homogeneous, perfectly smooth flint-glass, for the construction of object-glasses of extraordinary magnitude, was manufactured in the institutions of Utzschneider and Fraunhofer at Munich, and subsequently in those of Merz and Mahler; and in the establishments of Guinand and Bontems, (conducted for MM. Lerebours and Cauchoix,) in Switzerland and France. It will be sufficient in this historical sketch to mention, by way of example, the large refractors made under Fraunhofer's directions for the Observatories of Dorpat and Berlin, in which the clear aperture was 9·6 inches in diameter, with a focal length of 14·2 feet, and those executed by Merz and Mahler, for the Observatories of Pulkowa and Cambridge, in the United States of America;[32] they are both adjusted with object-glasses of 15 inches in diameter, and a focal length of 22·5 feet. The heliometer at the Konïgsberg Observatory, which continued for a long time to be the largest in existence, has an aperture of 6·4 inches in diameter. This instrument has been rendered celebrated by the memorable labours of Bessel. The well-illuminated and short dyalitic refractors which were first executed by Plösl in Vienna, and the advantages of which were almost simultaneously recognized by Rogers in England, are of sufficient merit to warrant their construction on a large scale.

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[31] Consult Struve, *Etudes d'Astr. stellaire*, 1847, note 59, p. 24. I have retained the designations of forty, twenty, and seven-feet Herschel reflecting telescopes, although in other parts of the work (the original German) I have used French measurements. I have adopted these designations not merely on account of their greater convenience, but also because they have acquired historical celebrity from the important labours both of the elder and younger Herschel in England, and of the latter at Feldhausen, at the Cape of Good Hope.

[32] See Schumacher's *Astr. Nachr.*, no. 371 and 611. Cauchoix

During this period, to the efforts of which I have referred, because they exercised so essential an influence on the extension of cosmical views, the improvements made in instruments of measurement (zenith sectors, meridian circles, and micrometers) were as marked in respect to mechanics as they were to optics and to the measurement of time. Among the many names distinguished in modern times in relation to instruments of measurement, we will here only mention those of Ramsden, Troughton, Fortin, Reichenbach, Gambey, Ertel, Steinheil, Repsold, Pistor, and Oertling; in relation to chronometers and astronomical pendulum clocks, we may instance Mudge, Arnold, Emery, Earnshaw, Breguet, Jürgensen, Kessels, Winnerl, and Tiede; while the noble labours of William and John Herschel, South, Struve, Bessel, and Dawes, in relation to the distances and periodic motions of the double stars, specially manifest the simultaneous perfection acquired in exact vision and measurement. Struve's classification of the double stars gives about 100 for the number whose distance from one another is below 1″, and 336

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and Lerebours have also constructed object-glasses of more than 13·3 inches in diameter, and nearly 25 feet focal length.

for those between 1″ and 2″; the measurement in every case being several times repeated.[33]

During the last few years, two men, unconnected with any industrial profession—the Earl of Rosse, at Parson's Town, (about fifty miles west of Dublin,) and Mr. Lassell, at Starfield, near Liverpool, have, with the most unbounded liberality, inspired with a noble enthusiasm for the cause of science, constructed under their own immediate superintendence two reflectors, which have raised the hopes of astronomers to the highest degree.[34] Lassell's telescope, which has an aperture only two feet in diameter, with a focal length of twenty feet, has already been the means of discovering one satellite of Neptune, and an eighth of Saturn, besides which two satellites of Uranus have been again distinguished. The new colossal telescope of Lord Rosse has an aperture of six feet, and is fifty-three feet in length. It is mounted in the meridian between two walls, distant twelve feet on either side from the tube, and from forty-eight to fifty-six feet in height. Many nebulæ, which had been irresolvable by any previous instruments, have been resolved into stellar swarms by this noble telescope; while the forms of other nebulæ have now, for the first time, been recognized in their true outlines. A marvellous effulgence is poured forth from the speculum.

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[33] Struve, *Stellarum duplicium et multiplicium Mensuræ micrometricæ*, pp. 2, 41.

[34] Mr. Airy has recently given a comparative description of the methods of constructing these two telescopes, including an account of the mixing of the metal, the contrivances adopted for casting and polishing the specula and mounting the instruments; *Abstr. of the Astr. Soc.*, vol. ix. no. 5, March, 1849. The effect of Lord Rosse's six-feet metallic reflector, is thus referred to. (p. 120.) "The Astronomer Royal, Mr. Airy, alluded to the impression made by the enormous light of the telescope: partly by the modifications produced in the appearances of nebulæ already figured, partly by the great number of stars seen even at a distance from the Milky Way, and partly from the prodigious brilliancy of *Saturn*. The account given by another astronomer of the appearance of *Jupiter* was, that it resembled a coach-lamp in the telescope; and this well expresses the blaze of light which is seen in the instrument." Compare also Sir John Herschel, *Outl. of Astr.*, § 870. "The sublimity of the spectacle afforded by the magnificent reflecting telescope constructed by Lord Rosse of some of the larger globular clusters of nebulæ is declared by all who have witnessed it, to be such as no words can express. This telescope has resolved or rendered resolvable multitudes of nebulæ which had resisted all inferior powers."

The idea of observing the stars by daylight with a telescope first occurred to Morin, who with Gascoigne (about 1638, before Picard and Auzout) combined instruments of measurement with the telescope. Morin himself says,[35] "It was not Tycho's great observations in reference to the position of the fixed stars, when, in 1582, twenty-eight years before the invention of the telescope, he was led to compare Venus by day with the sun, and by night with the stars," but "the simple idea that Arcturus and other fixed stars might, like Venus, when once they had been fixed in the field of the telescope before sunrise, be followed through the heavens, after the sun had risen, that led him to a discovery which might prove of importance for the determination of longitude at sea." No one was able before him to distinguish the fixed stars in the presence of the sun. Since the employment, by Römer, of great meridian telescopes in 1691, observations of the stars by day have been frequent and fruitful in results, having been, in some cases, advantageously applied to the measurement of the double stars. Struve states[36] that he has determined the smallest distances of extremely faint stars in the Dorpat refractor, with a power of only 320, in so bright a crepuscular light, that he could read with ease at midnight. The polar star has a companion of the 9th magnitude, which is situated at only 18″ distance: it was seen *by day* in the Dorpat refracting telescope, by Struve and Wrangel,[37] and was in like manner observed on one occasion by Encke and Argelander.

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[35] Delambre, *Hist. de l'Astron. moderne*, t. ii. p. 255.

[36] Struve, *Mens microm.* p. xliv

Many conjectures have been hazarded regarding the cause of the great power of the telescope at a time when the diffused light of the atmosphere, by multiplied reflection, exerts an obstructing action.[38] This question, considered as an

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[37] Schumacher's *Jahrbuch für* 1839, s. 100.

[38] *La lumière atmosphérique diffuse* ne peut s'expliquer par le reflet des rayons solaires sur la surface de séparation des couches de différentes densités dont on suppose l'atmosphère composée. En effet, supposons le soleil placé a l'horizon, les surfaces de séparation dans la direction du zenith seraient horizontales, par conséquent la réflexion serait horizontale aussi, et nous ne verrions aucune lumière au zénith. Dans la supposition des couches, aucun rayon ne nous arriverait par voie d'une première réflexion. Ce ne seraient que les réflexions multiples qui pourraient agir. Donc pour expliquer la *lumière diffuse*, il faut se figurer l'atmosphère composée de molécules (sphériques, par exemple) dont chacune donne une image du soleil à peu près comme les boules de verres que nous plaçons dans nos jardins. L'air pur est bleu, parceque d'après Newton, les molécules de l'air ont *l'épaisseur* qui convient à la réflexion des rayons bleus. Il est donc naturel que les petites images du soleil que de tous côtés réfléchissent les molécules sphériques de l'air et qui sont la lumière diffuse aient une teinte bleue: mais ce bleu n'est pas du bleu pur, c'est un blanc dans lequel le bleu prédomine. Lorsque le ciel n'est pas dans toute sa pureté et que l'air est mêlé de vapeurs visibles, la lumière diffuse reçoit beaucoup de blanc. Comme la lune est jaune, le bleu de l'air pendant la nuit est un peu verdâtre, c'est-à-dire, mélangé de bleu et de jaune."

"We cannot explain the *diffusion of atmospheric light* by optical problem, excited the strongest interest in the mind of Bessel, whose too early death was so unfortunate for the cause of science. In his long correspondence with myself, he frequently reverted to this subject, admitting that he could not arrive at any satisfactory solution. I feel confident it will not be unwelcome to my readers, if I subjoin, in the form of a note, some of the opinions of Arago,[39] as expressed in one of the

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the reflection of solar rays on the surface of separation of the strata of different density, of which we suppose the atmosphere to be composed. In fact, if we suppose the sun to be situated on the horizon, the surfaces of separation in the direction of the zenith will be horizontal, and consequently the reflection would likewise be horizontal, and we should not be able to see any light at the zenith. On the supposition that such strata exist, no ray would reach us by means of direct reflection. Repeated reflections would be necessary to produce any effect. In order, therefore, to explain the phenomenon of *diffused light,* we must suppose the atmosphere to be composed of molecules (of a spherical form, for instance), each of which presents an image of the sun somewhat in the same manner as an ordinary glass ball. Pure air is blue, because, according to Newton, the molecules of the air have the thickness necessary to reflect blue rays. It is therefore natural that the small images of the sun, reflected by the spherical molecules of the atmosphere, should present a bluish tinge; this colour is not, however, pure blue, but white, in which the blue predominates. When the sky is not perfectly pure and the atmosphere is blended with perceptible vapours, the diffused light is mixed with a large proportion of white. As the moon is yellow, the blue of the air assumes somewhat of a greenish tinge by night, or, in other words, becomes blended with yellow."—*MSS of* 1847.

[39] *D'un des Effets des Lunettes sur la Visibilité des étoiles.* (*Lettre de M. Arago à M. de Humboldt en Déc.* 1847.)

"L'œil n'est doué que d'une sensibilité circonscrite, bornée. Quand la lumière qui frappe la rétine, n'a pas assez d'intensité, l'œil ne sent rien. C'est par un manque d'intensité que beaucoup d'*étoiles*, même dans les nuits les plus profondes échappent à nos observations. Les lunettes ont pour effet,

numerous manuscripts to which I was permitted free access during my frequent sojourn in Paris. According to the ingenious explanation of my friend, high magnifying powers facilitate the discovery and recognition of the fixed stars, since

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*quant aux étoiles*, d'augmenter l'intensité de l'image. Le faisceau cylindrique de rayons parallèles venant d'une étoile, qui s'appuie sur la surface de la lentille objective, et qui a cette surface circulaire pour base, se trouve considérablement resserré à la sortie de la lentille oculaire. Le diamètre du premier cylindre est au diamètre du second, comme la distance focale de l'objectif est à la distance focale de l'oculaire, ou bien comme le diamètre de l'objectif est au diamètre *de la portion d'oculaire* qu'occupe le faisceau émergent. Les intensités de lumière dans les deux cylindres en question (dans les deux cylindres, incident et émergent) doivent être entr'elles comme les étendues superficielles des bases. Ainsi la lumière émergente sera plus condensée, *plus intense* que la lumière naturelle tombant sur l'objectif, dans le rapport de la surface de cet objectif à la surface circulaire de la base du faisceau émergent. Le faisceau *émergent*, *quand la lunette grossit*, étant plus étroit que le faisceau cylindrique qui tombe sur l'objectif, il est évident que la pupille, quelle que soit son ouverture, recueillera plus de rayons par l'intermédiaire de la lunette que sans elle. La lunette augmentera donc toujours l'intensité de la lumière *des étoiles*.

"Le cas *le plus favorable*, quant à l'effet des lunettes, est évidemment celui où l'œil reçoit la totalité du faisceau émergent, le cas où ce faisceau a moins de diamètre que la pupille. Alors *toute la lumière* que l'objectif embrasse, concourt, par l'entremise du télescope, à la formation de l'image. A l'œil nu, au contraire, *une portion* seule de cette même lumière est mise à profit; c'est la petite portion que la surface de la pupille découpe dans le faisceau incident naturel. L'intensité de l'image télescopique d'une étoile est donc à l'intensité de l'image à l'œil nu, *comme la surface de l'objectif est à celle de la pupille.*

"Ce qui précède est relatif à la visibilité d'un seul point, d'une seule étoile. Venons à l'observation d'un objêt ayant des dimensions angulaires sensibles, à l'observation d'une *planète.*

they convey a greater quantity of intense light to the eye without perceptibly enlarging the image; while, in accordance with another law, they influence the aerial space on which the fixed star is projected. The telescope, by separating,

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Dans les cas les plus favorables, c'est-à-dire lorsque la pupille reçoit la totalité du pinceau émergent, l'intensité de l'image *de chaque point* de la planète se calculera par la proportion que nous venons de donner. La quantité *totale de lumière* concourant a former *l'ensemble* de l'image à l'œil nu, sera donc aussi à la *quantité totale de lumière* qui forme l'image de la planète à l'aide d'une lunette, comme la surface de la pupille est à la surface de l'objectif. Les intensités comparatives, non plus de points isolés, mais des deux images d'une planète, qui se forment sur la rétine à l'œil nu, et par l'intermédiaire d'une lunette, doivent évidemment *diminuer* proportionnellement aux *étendues superficielles* de ces deux images. Les dimensions *linéaires* des deux images sont entr'elles comme le diamètre de l'objectif est au diamètre du faisceau émergent. Le nombre de fois que la *surface* de l'image amplifiée surpasse la *surface* de l'image à l'œil nu, s'obtiendra donc en divisant le carré du *diamètre* de l'*objectif* par le carré du *diamètre du faisceau émergent*, ou bien la *surface de l'objectif par la surface de la base circulaire du faisceau émergent.*

" Nous avons déjà obtenu le rapport des *quantités totales de lumière* qui engendrent les deux images *d'une planète*, en divisant la surface de l'objectif *par la surface de la pupille.* Ce nombre est *plus petit* que le quotient auquel on arrive en divisant la *surface de l'objectif* par la *surface du faisceau émergent.* Il en résulte, quant aux planètes, qu'une lunette fait moins gagner en intensité de lumière, qu'elle ne fait perdre en agrandissant *la surface* des images sur la rétine; l'intensité de ces images doit donc aller continuellement en s'affaiblissant à mesure que le pouvoir amplificatif de la lunette ou du télescope s'accroit.

" L'atmosphère peut être considérée comme une planète à dimensions indéfinies. La portion qu'on en verra dans une lunette, subira donc aussi la *loi* d'affaiblissement que nous venons d'indiquer. Le *rapport* entre l'intensité de la lumière d'une *planète* et le champ de lumière atmosphérique à travers

as it were, the illuminated particles of air surrounding the object-glass, darkens the field of view, and diminishes the intensity of its illumination. We are enabled to see, however, only by means of the difference between the

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lequel on la verra, sera le même à l'œil nu et dans les lunettes de tous les grossissements, de toutes les dimensions. Les lunettes, *sous le rapport de l'intensité*, ne favorisent donc pas la visibilité *des planètes*.

"Il n'en est point ainsi des *étoiles*. L'intensité de l'image d'une étoile est plus forte avec une lunette qu'à l'œil nu; au contraire, le champ de la vision, uniformément éclairé dans les deux cas par la lumière atmosphérique, est plus clair à l'œil nu que dans la lunette. Il y a donc deux raisons, sans sortir des considérations d'intensité, pour que dans une lunette l'image de l'étoile prédomine sur celle de l'atmosphère, notablement plus qu'à l'œil nu.

"Cette prédominance doit aller graduellement en augmentant avec le grossissement. En effet, abstraction faite de certaine augmentation du diamètre de l'étoile, conséquence de divers effets de *diffraction* ou d'*interférences*, abstraction faite aussi d'une plus forte réflexion que la lumière subit sur les surfaces plus obliques des oculaires de très courts foyers, l'*intensité de la lumière de l'étoile est constante* tant que l'ouverture de l'objectif ne varie pas. Comme on l'a vu, la *clarté du champ* de la lunette, au contraire, *diminue sans cesse* à mesure que le pouvoir amplificatif s'accroit. Donc toutes autres circonstances restant égales, une étoile sera d'autant plus visible, sa prédominence sur la lumière du champ du télescope sera d'autant plus tranchée qu'on fera usage d'un grossissement plus fort."

"The eye is endowed with only a limited sensibility; for when the light which strikes the retina is not sufficiently strong, the eye is not sensible of any impression. In consequence of deficient intensity, many stars escape our observation, even in the darkest nights. Telescopic glasses have the effect of augmenting the intensity of the images of the stars. The cylindrical pencil of parallel rays emanating from a star, and striking the surface of the object-glass, on whose circular surface it rests as on a base, is considerably light of the fixed star and of the aerial field or the mass of air which surrounds the star in the telescope. Planetary discs present very different relations from the simple ray of the image of a fixed star; since. like the aerial field (*l'air aërienne*),

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contracted on emerging from the eye-piece. The diameter of the first cylinder is to that of the second as the focal distance of the object-glass is to the focal distance of the eye-piece, or as the diameter of the object-glass is to the diameter of the part of the eye-piece covered by the emerging rays. The intensities of the light in these two cylinders (the incident nd emerging cylinders) must be to one another as the superficies of their bases. Thus, the emerging light will be more condensed, more *intense*, than the natural light falling on the object-glass, in the ratio of the surface of this object-glass to the circular surface of the base of this emerging pencil. As the *emerging pencil* is narrower in a magnifying instrument than the cylindrical pencil falling on the object-glass, it is evident that the pupil, whatever may be its aperture, will receive more rays, by the intervention of the telescope, than it could without. The intensity of the light of the stars will, therefore, always be augmented, when seen through a telescope.

"The most favourable condition for the use of a telescope is undoubtedly that in which the eye receives the whole of the emerging rays, and, consequently, when the diameter of the pencil is less than that of the pupil. The *whole of the light* received by the object-glass then co-operates, through the agency of the telescope, in the formation of the image. In natural vision, on the contrary, a portion only of this light is rendered available, namely, the small portion which enters the pupil naturally from the incident pencil. The intensity of the telescopic image of a star is, therefore, to the intensity of the image seen with the naked eye, as the *surface of the object-glass is to that of the pupil.*

"The preceding observations relate to the visibility of one point, or one star. We will now pass on to the consideration of an object having sensible angular dimensions, as, for instance, a *planet*. Under the most favourable conditions of vision, that is to say, when the pupil receives the whole of the emerging pencil, the intensity of *each point* of the they lose in intensity of light by dilatation in the magnifying telescope. It must be further observed, that the apparent motion of the fixed star, as well as of the planetary disc, is increased by high magnifying powers. This circumstance may

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planet's image may be calculated by the proportions we have already given. The *total quantity of light* contributing to form the whole of the image, as seen by the naked eye, will, therefore, be to the *total quantity* of the light forming the image of the planet by the aid of a telescope, as the surface of the pupil is to the surface of the object-glass. The comparative intensities, not of mere isolated points, but of the images of a planet formed respectively on the retina of the naked eye, and by the intervention of a telescope, must evidently diminish proportionally to the superficial extent of these two images. The linear dimensions of the two images are to one another as the diameter of the object-glass is to that of the emerging pencil. We therefore obtain the number of times that the *surface* of the magnified image exceeds the *surface* of the image when seen by the naked eye by dividing the *square of the diameter of the object-glass by the square of the diameter of the emerging pencil*, or rather the *surface of the object-glass by the surface of the circular base of the emerging pencil.*

"By dividing the surface of the object-glass by the surface of the pupil, we have already obtained the ratio of the total quantities of light produced by the two images of a planet. This number is lower than the quotient which we obtain by dividing the surface of the object-glass by the surface of the emerging pencil. It follows, therefore, with respect to planets, that a telescope causes us to gain less in intensity of light than is lost by magnifying the surface of the images on the retina; the intensity of these images must therefore become continually fainter, in proportion as the magnifying power of the telescope increases.

"The atmosphere may be considered as a planet of indefinite dimensions. The portion of it that we see in a telescope will therefore also be subject to the same law of diminution that we have indicated The relation between the intensity of the light of a planet and the field of atmospheric light through facilitate the recognition of objects by day, in instruments whose movements are not regulated paralactically by clockwork, so as to follow the diurnal motion of the heavens. Different points of the retina are successively excited. "Very faint shadows are not observed," Arago elsewhere remarks, "until we can give them motion."

In the cloudless sky of the tropics, during the driest season

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which it is seen, will be the same to the naked eye and in telescopes, whatever may be their dimensions and magnifying powers. Telescopes, therefore, do not favour the visibility of planets in respect to the intensity of their light.

"The same is not the case with respect to the stars. The intensity of the image of a star is greater when seen with the telescope than with the naked eye; the field of vision, on the contrary, uniformly illumined in both cases by the atmospheric light, is clearer in natural than in telescopic vision. There are two reasons then, which, in connexion with the consideration of the intensity of light, explain why the image of a star preponderates in a telescope rather than in the naked eye over that of the atmosphere.

"This predominance must gradually increase with the increased magnifying power. In fact, deducting the constant augmentation of the star's diameter, consequent upon the different effects of diffraction or interference, and deducting also the stronger reflection experienced by the light on the more oblique surfaces of ocular glasses of short focal lengths, *the intensity of the light of the star is constant*, as long as the aperture of the object-glass does not vary. As we have already seen, the brightness of the field of view, on the contrary, diminishes incessantly in the same ratio in which the magnifying power increases. All other circumstances, therefore, being equal, a star will be more or less visible, and its prominence on the field of the telescope will be more or less marked, in proportion to the magnifying powers we employ." Arago, *Manuscript of* 1847.

I will further add the following passage from the *Annuaire du Bureau des Long. pour* 1846 (*Notices Scient. par M. Arago*), p. 381.

of the year, I have frequently been able to find the pale disc of Jupiter with one of Dolland's telescopes, of a magnifying power of only 95, when the sun was already from 15° to 18° above the horizon. The diminished intensity of the light of Jupiter and Saturn, when seen by day in the great Berlin refractor, especially when contrasted with the equally reflected light of the inferior planets, Venus and Mercury, frequently excited the astonishment of Dr. Galle. Jupiter's occul-

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"L'expérience a montré que pour le commun des hommes, deux espaces éclairés et contigus ne se distinguent pas l'un de l'autre, à moins que leurs intensités comparatives ne présentent, au minimum, une différence de $\frac{1}{60}$. Quand une lunette est tournée vers le firmament, son champ semble uniformement éclairé: c'est qu' alors il existe, dans un plan passant par le foyer et perpendiculaire à l'axe de l'objectif, une *image indéfinie* de la région atmosphérique vers laquelle la lunette est dirigée. Supposons qu'un astre, c'est-à-dire un objet situé bien au-delà de l'atmosphère, se trouve dans la direction de la lunette: son image ne sera visible qu'autant qu'elle augmentera de $\frac{1}{60}$, au moins, l'intensité de la portion de l'image focale *indéfinie* de l'atmosphère, sur laquelle sa propre image *limitée* ira se placer. Sans cela, le champ visuel continuera a *paraître* partout de la même intensité."

"Experience has shown that, in ordinary vision, two illuminated and contiguous spaces cannot be distinguished from each other, unless their comparative intensities present a minimum difference of $\frac{1}{60}$th. When a telescope is directed towards the heavens, its field of view appears uniformly illumined: there then exists in a plane passing through the focus, and perpendicular to the axis of the object-glass, *an indefinite image* of the atmospheric region towards which the instrument is pointed. If we suppose a star, that is to say, an object very far beyond the atmosphere, situated in the direction of the telescope, its image will not be visible, except it exceed, by at least $\frac{1}{60}$th, the intensity of that portion of the indefinite focal image of the atmosphere on which its *limited* proper image is thrown. Otherwise, the visual field will continue to appear everywhere of the same intensity."

tations have occasionally been observed by daylight, with the aid of powerful telescopes, as in 1792, by Flaugergues, and in 1820, by Struve. Argelander (on the 7th of December, 1849, at Bonn) distinctly saw three of the satellites of Jupiter, a quarter of an hour after sunrise, with one of Fraunhofer's five-feet telescopes. He was unable to distinguish the fourth; but, subsequently, this and the other satellites were observed emerging from the dark margin of the moon, by the assistant-astronomer, Schmidt, with the eight-feet heliometer. The determination of the limits of the telescopic visibility of small stars by daylight, in different climates, and at different elevations above the sea's level, is alike interesting in an optical and a meteorological point of view.

Among the remarkable phenomena whose causes have been much contested, in natural as well as in telescopic vision, we must reckon the nocturnal scintillation of the stars. According to Arago's investigations, two points must be specially distinguished in reference to this phenomenon[40]—

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[40] The earliest explanations given by Arago of scintillation occur in the appendix to the 4th book of my *Voyage aux Régions équinoxiales*, tom. i, p. 623. I rejoice that I am able to enrich this section on natural and telescopic vision, with the following explanations, which, for the reasons already assigned, I subjoin in the original text.

*Des causes de la scintillation des étoiles.*

"Ce qu'il y a de plus remarquable dans le phénomène de la scintillation, c'est le changement de couleur. Ce changement est beaucoup plus fréquent que l'observation ordinaire l'indique. En effet, en agitant la lunette, on transforme l'image dans une ligne ou un cercle, et tous les points de cette ligne ou de ce cercle paraissent de couleurs différentes. C'est la résultante de la superposition de toutes ces images que l'on voit, lorsqu'on laisse la lunette immobile. Les rayons qui se réunissent au foyer d'une lentille, vibrent d'accord ou en désaccord, s'ajoutent ou se détruisent, suivant que les couches

Firstly, Change in the intensity of the light, from a sudden decrease to perfect extinction and rekindling; Secondly, Change of colour. Both these alterations are more intense in reality than they appear to the naked eye; for when the several points of the retina are once excited, they retain the impression of light which they have received, so that the disappearance,

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qu'ils ont traversées, ont telle ou telle réfringence. L'ensemble des rayons rouges peut se détruire *seul*, si ceux de droite et de gauche, et ceux de haut et de bas, ont traversé des milieux inégalement réfringents. Nous avons dit *seul*, parceque la différence de réfringence qui correspond à la destruction du rayon rouge, n'est pas la même que celle qui amène la destruction du rayon vert, et réciproquement. Maintenant, si des rayons rouges sont détruits, ce qui reste sera le blanc moins le rouge, c'est-à-dire du vert. Si le vert au contraire est détruit par *interférence*, l'image sera du blanc moins le vert, c'est-à-dire du rouge. Pour expliquer pourquoi les planètes à grand diamètre ne scintillent pas ou très peu, il faut se rappeler que le disque peut être considéré comme une aggrégation d'étoiles ou de petits points qui scintillent isolément; mais les images de différentes couleurs que chacun de ces points pris isolément donnerait, empiétant les unes sur les autres, formeraient du blanc. Lorsqu'on place un diaphragme ou un bouchon percé d'un trou sur l'objectif d'une lunette, les étoiles acquièrent un disque entouré d'une série d'anneaux lumineux. Si l'on enfonce l'oculaire, le disque de l'étoile augmente de diamètre, et il se produit dans son centre un trou obscur; si on l'enfonce davantage, un point lumineux se substitue au point noir. Un nouvel enfoncement donne naissance à un centre noir, etc. Prenons la lunette lorsque le centre de l'image est noir, et visons à une étoile qui ne scintille pas: le centre restera noir, comme il l'était auparavant. Si au contraire on dirige la lunette à une étoile qui scintille, on verra le centre de l'image lumineux et obscur par intermittence. Dans la position où le centre de l'image est occupé par un point lumineux, on verra ce point disparaître et renaître successivement. Cette disparition ou réapparition du point central est la preuve directe de l'*interférence* variable des rayons. Pour bien concevoir l'absence de lumière au centre de ces images dilatees,

obscuration, and change of colour, in a star, are not perceived by us to their full extent. The phenomenon of scintillation is more strikingly manifested in the telescope, when the instrument is shaken, for then different points of the retina are successively excited, and coloured and frequently interrupted rings are seen. The principle of interference explains

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il faut se rappeler que les rayons régulièrement réfractés par l'objectif ne se réunissent et ne peuvent par conséquent *interfèrer* qu'au foyer : par conséquent les images dilatées que ces rayons peuvent produire, resteraient toujours pleines (sans trou). Si dans une certaine position de l'oculaire un trou se présente au centre de l'image, c'est que les rayons régulièrement réfractés *interfèrent* avec des rayons *diffractés* sur les bords du diaphragme circulaire. Le phénomène n'est pas constant, parceque les rayons qui interfèrent dans un certain moment, n'interfèrent pas un instant après, lorsqu'ils ont traversé des couches atmosphériques dont le pouvoir réfringent a varié. On trouve dans cette expérience la preuve manifeste du rôle que joue dans le phénomène de la scintillation l'inégale réfrangibilité des couches atmosphériques traversées par les rayons dont le faisceau est très étroit. Il résulte de ces considérations que l'explication des scintillations ne peut être rattachée qu'aux phénomènes des *interfèrences lumineuses.* Les rayons des étoiles, apres avoir traversé une atmosphère où il existe des couches inégalement chaudes, inégalement denses, inégalement humides, vont se réunir au foyer d'une lentille, pour y former des images d'intensité et de couleurs perpétuellement changeantes, c'est-à-dire des images telles que la scintillation les présente. Il y a aussi scintillation hors du foyer des lunettes. Les explications proposées par Galileo, Scaliger, Kepler, Descartes, Hooke, Huygens, Newton et John Michell. que j'ai examiné dans un mémoire présenté à l'Institut en 1840 (*Comptes rendus*, t. x. p. 83), sont inadmissibles. Thomas Young, auquel nous devons les premières lois des interfèrences, a cru inexplicable le phénomène de la scintillation. La fausseté de l'ancienne explication par des vapeurs qui voltigent et déplacent, est déjà prouvée par la circonstance que nous voyons la scintillation des yeux, ce qui supposerait un déplacement d'une minute. Les ondula-

how the momentary coloured effulgence of a star may be followed by its equally instantaneous disappearance or sudden obscuration, in an atmosphere composed of ever-changing strata of different temperatures, moisture, and density. The undulatory theory teaches us generally that two rays of light (two systems of waves) emanating from one source (one centre

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tions du bord du soleil sont de 4″ à 5″, et peut-être des pièces qui *manquent*, donc encore effet de l'interfèrence des rayons."

*On the causes of the scintillation of the stars.*

"The most remarkable feature in the phenomenon of the stars' scintillation is their change of colour. This change is of much more frequent occurrence than would appear from ordinary observation. Indeed, on shaking the telescope the image is transformed into a line or circle, and all the points of this line or circle appear of different colours. We have here the results of the superposition of all the images seen when the telescope is at rest. The rays united in the focus of a lens, vibrate in harmony or at variance with one another, and increase or destroy one another according to the various degrees of refraction of the strata through which they have passed. The whole of the red rays alone can destroy one another, if the rays to the right and left, above and below them have passed through unequally refracting media. We have used the term *alone*, because the difference of refraction necessary to destroy the red ray is not the same as that which is able to destroy the green ray, and *vice versa*. Now, if the red rays be destroyed, that which remains will be white minus red, that is to say green. If the green on the other hand be destroyed by *interference*, the image will be white minus green, that is to say red. To understand why planets having large diameters should be subject to little or no scintillation, it must be remembered that the disc may be regarded as an aggregation of stars, or of small points, scintillating independently of each other, while the images of different colours presented by each of these points taken alone would impinge upon one another and form white. If we place a diaphragm or a cork pierced with a hole on the object-glass of a telescope, the stars present a disc surrounded by a series of luminous rings.

of commotion), destroy each other by inequality of path; that the light of one ray added to the light of the other produces darkness. When the retardation of one system of waves in reference to the other amounts to an odd number of semi-undulations, both systems endeavour to impart simultaneously to the same molecule of ether equal but opposite velocities; so that the effect of their combination is to produce rest in the molecule, and therefore darkness. In some cases,

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On pushing in the eye-piece, the disc of the star increases in diameter and a dark point appears in its centre; when the eye-piece is made to recede still further into the instrument, a luminous point will take the place of the dark point. On causing the eye-piece to recede still further, a black centre will be observed. If while the centre of the image is black we point the instrument to a star which does not scintillate, it will remain black as before. If, on the other hand, we point it to a scintillating star, we shall see the centre of the image alternately luminous and dark. In the position in which the centre of the image is occupied by a luminous point, we shall see this point alternately vanish and reappear. This disappearance and reappearance of the central point is a direct proof of the variable interference of the rays. In order to comprehend the absence of light from the centre of these dilated images, we must remember that rays regularly refracted by the object-glass do not reunite and cannot consequently interfere except in the focus; thus the images produced by these rays will always be uniform and without a central point. If in a certain position of the eye-piece, a point is observed in the centre of the image, it is owing to the interference of the regularly refracted rays with the rays *diffracted* on the margins of the circular diaphragm. The phenomenon is not constant, for the rays which interfere at one moment no longer do so in the next, after they have passed through atmospheric strata possessing a varying power of refraction. We here meet with a manifest proof of the important part played in the phenomenon of scintillation by the unequal refrangibility of the atmospheric strata traversed by rays united in a very narrow pencil."

the refrangibility of the different strata of air intersecting the rays of light exerts a greater influence on the phenomenon than the difference in length of their path.[41]

The intensity of scintillations varies considerably in the different fixed stars, and does not seem to depend solely on their altitude and apparent magnitude, but also on the nature of their own light. Some, as for instance Vega, flicker less than Arcturus and Procyon. The absence of scintillation in planets with larger discs, is to be ascribed to compensation and to the neutralizing mixture of colours proceeding from different points of the disc. The disc is to be regarded as an aggregate of stars which naturally compensate for the light destroyed by interference, and again combine the

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"It follows from these considerations that scintillation must necessarily be referred to the phenomena of *luminous interferences* alone. The rays emanating from the stars, after traversing an atmosphere composed of strata having different degrees of heat, density, and humidity, combine in the focus of a lens, where they form images perpetually changing in intensity and colour, that is to say, the images presented by scintillation. There is another form of scintillation, independent of the focus of the telescope. The explanations of this phenomenon advanced by Galileo, Scaliger, Kepler, Descartes, Hooke, Huygens, Newton, and John Michell, which I examined in a memoir presented to the institute in 1840 (*Comptes Rendus*, t. x. p. 83), are inadmissible. Thomas Young, to whom we owe the discovery of the first laws of interference, regarded scintillation as an inexplicable phenomenon. The erroneousness of the ancient explanation which supposes that vapours ascend and displace one another, is sufficiently proved by the circumstance that we see scintillations with the naked eye, which presupposes a displacement of a minute. The undulations of the margin of the sun are from 4″ to 5″, and are perhaps owing to chasms or interruptions and therefore also to the effect of interference of the rays of light." (*Extracts from Arago's MSS. of* 1847.)

[41] See Arago, in the *Annuaire pour* 1831, p. 168.

coloured rays into white light. For this reason we most rarely meet with traces of scintillation in Jupiter and Saturn, but more frequently in Mercury and Venus, for the apparent diameters of the discs of these last named planets diminish to 4″·4 and 9″·5. The diameter of Mars may also decrease to 3″·3 at its conjunction. In the serene cold winter nights of the temperate zone, the scintillation increases the magnificent impression produced by the starry heavens, and the more so from the circumstance that, seeing stars of the 6th and 7th magnitude flickering in various directions, we are led to imagine that we perceive more luminous points than the unaided eye is actually capable of distinguishing. Hence the popular surprise at the few thousand stars which accurate catalogues indicate as visible to the naked eye! It was known in ancient times by the Greek astronomers, that the flickering of their light distinguished the fixed stars from the planets; but Aristotle, in accordance with the emanation and tangential theory of vision, to which he adhered, singularly enough ascribes the scintillation of the fixed stars merely to a straining of the eye. "The rivetted stars (the fixed stars)," says he,[42] "sparkle, but not the planets: for the latter are so near, that the eye is able to reach them; but in looking at the fixed stars (*πρὸς δὲ τους μένοντας*) the eye acquires a tremulous motion owing to the distance and the effort."

In the time of Galileo, between 1572 and 1604,—an epoch remarkable for great celestial events, when three stars[43] of greater brightness than stars of the first magnitude suddenly appeared, one of which, in Cygnus, remained luminous for twenty-one years,—Kepler's attention was specially directed to scintillation as the probable criterion of the non-planetary nature of a celestial body. Although well versed in the science of optics, in its then imperfect state, he was unable to rise above the received notion of moving vapours.[44] In the Chinese Records of the newly appeared stars, according to the great collection of Ma-tuan-lin, their strong scintillation is occasionally mentioned.

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[42] Aristot. *de Cœlo*, ii. 8, p. 290, Bekker.

[43] *Cosmos*, vol. ii. p. 709.

The more equal mixture of the atmospheric strata, in and near the tropics, and the faintness or total absence of scintillation of the fixed stars when they have risen 12° or 15° above the horizon, give the vault of heaven a peculiar character of mild effulgence and repose. I have already referred in many of my delineations of tropical scenery to this characteristic, which was also noticed by the accurate observers, La Condamine and Bouguer, in the Peruvian plains, and by Garcin,[45] in Arabia, India, and on the shores of the Persian Gulf (near Bender Abassi).

As the aspect of the starry heavens, in the season of the serene and cloudless nights of the tropics, specially excited my admiration, I have been careful to note in my journals the height above the horizon at which the scintillation of the stars ceased in different hygrometric conditions. Cumana and the rainless portion of the Peruvian coast of the Pacific, before the season of the *garua* (mist) had set in, were peculiarly suited to such observations. On an average the fixed stars appear only to scintillate when less than 10° or 12° above the horizon. At greater elevations, they shed a mild, planetary light; but this difference is most strikingly perceived, when the same fixed stars are watched in their gradual rising or setting, and the angles of their altitudes measured, or calculated by the known time and latitude of the place. In some serene and calm nights, the region of scintillation extended to an elevation of 20° or even 25°; but a connection could scarcely ever be traced between the differences of altitude or intensity of the scintillation and the hygrometric and thermometric conditions, observable in the lower and only accessible region of the atmosphere. I have observed, during successive nights, after considerable scintillation of stars, having an altitude of 60° or 70°, when Saussure's hair-hygrometer stood at 85°, that the scintillation entirely ceased when the stars were 15° above the horizon, although the moisture of the atmosphere was so considerably increased that the hygrometer had risen to 93°. The intricate compensatory phenomena of interference of the rays of light are modified, not by the quantity of aqueous vapour contained in solution in the atmosphere, but by the unequal distribution of vapours in the superimposed strata, and by the upper currents of cold and warm air, which are not perceptible in the lower regions of the atmosphere. The scintillation of stars at a great altitude was also strikingly increased during the thin yellowish red mist, which tinges the heavens shortly before an earthquake. These observations only refer to the serenely bright and rainless seasons of the year, within the tropics, from 10° to 12° north and south of the equator. The phenomena of light exhibited at the commencement of the rainy season, during the sun's zenith-passage, depend on very general, yet powerful, and almost tempestuous causes. The sudden decrease of the north-east trade-wind, and the interruption of the passage of regular upper currents from the equator to the poles, and of lower currents from the poles to the equator, generate clouds, and thus daily give rise, at definite recurring periods, to storms of wind and torrents of rain. I have observed during several successive years that in regions where the scintillation of the fixed stars is of rare occurrence, the approach of the rainy season is announced many days beforehand, by a flickering light of the stars at great altitudes above the horizon. This phenomenon is accompanied by sheet lightning, and single flashes on the distant horizon, sometimes without any visible cloud, and at others darting through narrow, vertically ascending columns of clouds. In several of my writings I have endeavoured to delineate these precursory characteristics and physiognomical changes in the atmosphere.[46]

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[44] *Causæ scintillationis*, in Kepler, *De Stella nova in pede Serpentarii*, 1606, cap. xviii. pp. 92–97.

[45] *Lettre de M. Garcin, Dr. en Med. à M. de Réaumur* in *Hist. de l'Académie Royale des Sciences, Année* 1743, pp. 28–32.

The second book of Lord Bacon's *Novum Organum* gives us the earliest views on the velocity of light and the probability of its requiring a certain time for its transmission. He speaks of the time required by a ray of light to traverse the enormous distances of the universe, and proposes the question whether those stars yet exist which we now see shining.[47] We are astonished to meet with this happy conjecture in a work whose intellectual author was far behind his contemporaries in mathematical, astronomical, and physical knowledge. The velocity of *reflected* solar light was first measured by Römer, (November, 1675,) by comparing the periods of occultation of Jupiter's satellites; while the velocity of the *direct* light of the fixed stars was ascertained (in the autumn of 1727) by means of Bradley's great discovery of aberration, which afforded *objective* evidence of the translatory movement of the earth, and of the truth of the Copernican system. In recent times a third method of measurement has been suggested by Arago, which is based on the phenomena of light observed in a variable star, as, for instance, Algol in Perseus.[48] To these astronomical methods may be added one

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[46] See *Voyage aux Régions équin.*, t. i. pp. 511 and 512, and t. ii. pp. 202–208; also my *Views of Nature*, pp. 16, 138.

"En Arabie, de même qu'à Bender-Abassi, port fameux du Golfe Persique, l'air est parfaitement serein presque toute l'année. Le printemps, l'été, et l'automne se passent, sans qu'on y voie la moindre rosée. Dans ces mêmes temps tout le monde couche dehors sur le haut des maisons. Quand on est ainsi couché, il n'est pas possible d'exprimer le plaisir qu'on prend à contempler la beauté du ciel, l'éclat des étoiles. C'est une lumière pure, ferme et éclatante, sans étincellement. Ce n'est qu'au milieu de l'hiver que la scintillation, quoique très foible, s'y fait apercevoir."

"In Arabia," says Garcin, "as also at Bender-Abassi, a celebrated port on the Persian Gulf, the air is perfectly serene throughout nearly the whole of the year. Spring, summer, and autumn, pass without exhibiting a trace of dew. During these seasons all the inhabitants sleep on the roofs of their houses. It is impossible to describe the pleasure experienced in contemplating the beauty of the sky, and the brightness of the stars, while thus lying in the open air. The light of the stars is pure, steady, and brilliant; and it is only in the middle of the winter, that a slight degree of scintillation is observed." Garcin, in *Hist. de l'Acad. des Sc.*, 1743, p. 30.

[47] In speaking of the deceptions occasioned by the velocity of

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sound and light, Bacon says:—"This last instance, and others of a like nature, have sometimes excited in us a most marvellous doubt, no less than whether the image of the sky and stars is perceived as at the actual moment of its existence, or rather a little after, and whether there is not (with regard to the visible appearance of the heavenly bodies) a true and apparent place which is observed by astronomers in parallaxes. It appeared so incredible to us that the images or radiations of heavenly bodies could suddenly be conveyed through such immense spaces to the sight, and it seemed that they ought rather to be transmitted in a definite time. That doubt, however, as far as regards any great difference between the true and apparent time, was subsequently completely set at rest, when we considered. . . . ." The works of Francis Bacon, vol. xiv. Lond. 1831 (*Novum Organum*), p. 177. He then recals the correct view he had previously announced precisely in the manner of the ancients. Compare Mrs. Somerville's *Connexion of the Physical Sciences*, p. 36; and *Cosmos*, vol. i. p. 145.

[48] See Arago's explanation of his method in the *Annuaire du Bureau des Longitudes pour* 1842, pp. 337–343. "L'observation attentive des phases d'Algol à six mois d'intervalle servira à déterminer directement la vitesse de la lumière de cette étoile. Près du maximum et du minimum le changement d'intensité s'opère lentement; il est au contraire rapide à certaines époques intermédiares entre celles qui corresp

of terrestrial measurement, lately conducted with much ingenuity and success by M. Fizeau in the neighbourhood of Paris. It reminds us of Galileo's early and fruitless experiments with two alternately obscured lanterns.

Horrebow and Du Hamel estimated the time occupied in the passage of light from the sun to the earth at its mean distance, according to Römer's first observations of Jupiter's satellites, at 14′ 7″, Cassini, at 14′ 10″; while Newton[49]

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dent aux deux états extrêmes, quand Algol, soit en diminuant, soit en augmentant d'éclat, passe pour la troisième grandeur."

"The attentive observation of the phases of Algol at a six-month interval will serve to determine directly the velocity of that star's light. Near the maximum and the minimum the change of intensity is very slow; it is, on the contrary, rapid at certain intermediate epochs between those corresponding to the two extremes, when Algol, either diminishing or increasing in brightness, appears of the third magnitude.

[49] Newton, *Opticks*, 2nd ed. (London, 1718), p. 325. "Light moves from the sun to us in seven or eight minutes of time." Newton compares the velocity of sound (1140 feet in 1″) with that of light. As, from observations on the occultations of Jupiter's satellites (Newton's death occurred about half a year before Bradley's discovery of aberration) he calculates that light passes from the sun to the earth, a distance, as he assumed, of 70 millions of miles, in 7′ 30″; this result yields a velocity of light equal to $155555\frac{5}{9}$ miles in a second. The reduction of these [ordinary] to geographical miles (60 to 1°) is subject to variations according as we assume the figure of the earth. According to Encke's accurate calculations in the *Jahrbuch für* 1852, an equatorial degree is equal to 69·1637 English miles. According to Newton's data we should therefore have a velocity of 134944 geographical miles. Newton however assumed the sun's parallax to be 12″. If this, according to Encke's calculation of the transit of Venus, be 8″·57116, the distance is greater, and we obtain for the velocity of light (at seven and a half minutes) 188928 geographical, or 217783 ordinary miles, in a second of time; therefore too much, as before we had too little. It is certainly very remarkable, although the circumstance has been over-

approximated very remarkably to the truth when he gave it at 7′ 30″. Delambre,[50] who did not take into account any of the observations made in his own time, with the

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looked by Delambre (*Hist. de l'Astronomie Moderne*, tom. ii. p. 653,) that Newton (probably basing his calculations upon more recent English observations of the first satellite) should have approximated within 47″ to the true result, (namely, that of Struve, which is now generally adopted,) while the time assigned for the passage of light over the semi-diameter of the earth's orbit continued to vacillate between the very high amounts of 11′ and 14′ 10″, from the period of Römer's discovery, in 1675, to the beginning of the 18th century. The first treatise in which Römer, the pupil of Picard, communicated his discovery to the Academy, bears the date of November, 22, 1675. He found, from observations of forty emersions and immersions of Jupiter's satellites, "a retardation of light amounting to 22 minutes for an interval of space, double that of the sun's distance from the earth." (*Mémoires de l'Acad. de* 1666–1699, tom. x. 1730, p. 400.) Cassini does not deny the retardation, but he does not concur in the amount of time given, because, as he erroneously argues, different satellites presented different results. Du Hamel, secretary to the Paris Academy, (*Regiæ Scientiarum Academiæ Historia*, 1698, p. 143,) gave from 10 to 11 minutes, seventeen years after Römer had left Paris, although he refers to him; yet we know, through Peter Horrebow (*Basis Astronomiæ sive Triduum Roemerianum*, 1735, pp. 122-129), that Römer adhered to the result of 11′, when in 1704, six years before his death, he purposed bringing out a work on the velocity of light; the same was the case with Huygens (*Tract. de Lumine*, cap. i. p. 7). Cassini's method was very different; he found 7′ 5″ for the first satellite, and 14′ 12″ for the second, having taken 14′ 10″ for the basis of his tables for Jupiter *pro peragrando diametri semissi*. The error was therefore on the increase. (Compare Horrebow, *Triduum*, p. 129; Cassini, *Hypothèses et Satellites de Jupiter* in the *Mém. de l'Acad.*, 1666-1699, tom. viii. pp. 435, 475; Delambre, *Hist. de l'Astr. mod.*, tom. ii. pp. 751, 782; Du Hamel, *Physica*, p. 435.)

[50] Delambre, *Hist. de l'Astr. mod.*, tom. ii. p. 653.

exception of those of the first satellite, found 8′ 13″·2 Encke has very justly noticed the great importance of undertaking a special course of observations on the occultations of Jupiter's satellites, in order to arrive at a correct idea regarding the velocity of light, now that the perfection attained in the construction of telescopes warrants us in hoping that we may obtain trustworthy results.

Dr. Busch,[51] of Königsberg, who based his calculations on Bradley's observations of aberration, as re-discovered by Rigaud of Oxford, estimated the passage of light from the sun to the earth at 8′ 12″·14, the velocity of stellar light at 167976 miles in a second, and the constant of aberration at 20″·2116; but it would appear, from the more recent observations on aberration carried on during eighteen months by Struve with the great transit instrument at Pulkowa,[52] that the former of these numbers should be considerably increased. The result of these important observations gave 8′ 17″·78; from which, with a constant of aberration of 20″·4451, and Encke's correction of the sun's parallax in the year 1835, together with his determination of the earth's radius, as given in his *Astronomisches Jahrbuch für* 1852, we obtain 166196 geographical miles for the velocity of light in a second. The probable error in the velocity seems scarcely to amount to eight geographical miles. Struve's result for the time which light requires to pass from the sun to the earth differs about $\frac{1}{110}$th from Delambre's (8′ 13″·2), which has been adopted by Bessel in the *Tab. Regiom.*, and has hitherto been followed in the Berlin Astronomical Almanack. The discussion on this subject cannot, however, be regarded as wholly at rest. Great doubts still exist as to the earlier adopted conjecture that the velocity of the light of the polar star was smaller than that of its companion in the ratio of 133 to 134.

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[51] *Reduction of Bradley's observations at Kew and Wansted*, 1836, p. 22; Schumacher's *Astr. Nachr.*, bd. xiii. 1836, no. 309; (compare *Miscellaneous Works and Correspondence of the Rev. James Bradley*, by Prof. Rigaud, Oxford, 1832). On the mode adopted for explaining aberration in accordance with the theory of undulatory light, see Doppler in the *Abhl. der Kön. böhmischen Gesellschaft der Wiss.* 5te Folge. bd. iii. s. 754-765. It is a point of extreme importance in the history of great astronomical discoveries, that Picard, more than half a century before the actual discovery and explanation by Bradley of the cause of aberration, probably from 1667, had observed a periodical movement of the Polar star to the extent of about 20″, which could "neither be the effect of parallax or of refraction, and was very regular at opposite seasons of the year." (Delambre, *Hist. de l'Astr. moderne*, tom. ii. p. 616.) Picard had nearly ascertained the velocity of direct light before his pupil, Römer, made known that of reflected light.

[52] Schum. *Astr. Nachr.*, bd. xxi. 1844, no. 484; Struve, *Etudes d'Astr. stellaire*, pp. 103, 107 (compare *Cosmos*, vol. i. p. 144.) The result given in the *Annuaire pour* 1842, p. 287, for the velocity of light in a second, is 308000 kilomenes, or 77000 leagues (each of 4000 metres), which corresponds

M. Fizeau, a physicist, distinguished alike for his great acquirements and for the delicacy of his experiments, has submitted the velocity of light to a terrestrial measurement, by means of an ingeniously constructed apparatus, in which artificial light (resembling stellar light) generated from oxygen and hydrogen, is made to pass back by means of a mirror between Suresne and La Butte Montmartre, over a distance of 28321 feet to the same point from which it emanated. A disc having 720 teeth, which made 12·6 rotations in a second, alternately ob-

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to 215834 miles, and approximates most nearly to Struve's recent result, while that obtained at the Pulkowa Observatory is 189746 miles. On the difference in the aberration of the light of the Polar star and that of its companion, and on the doubts recently expressed by Struve, see Mädler, *Astronomie*, 1849, s. 393. William Richardson gives as the result of the passage of light from the sun to the earth 8′ 19″·28, from which we obtain a velocity of 215392 miles in a second. (*Mem. of the Astron. Soc.*, vol. iv. P. i. p. 68.)

scured the ray of light and allowed it to be seen between the teeth on the margin. It was supposed from the marking of a counter (compteur) that the artificial light traversed 56642 feet, or the distance to and from the stations in $\frac{1}{18000}$th part of a second, whence we obtain a velocity of 191460 miles in a second.[53] This result therefore approximates most closely to Delambre's (which was 189173 miles) as obtained from Jupiter's satellites.

Direct observations and ingenious reflections on the absence of all coloration during the alternation of light in the *variable stars*—a subject to which I shall revert in the sequel—led Arago to the result, that, according to the undulatory theory, rays of light of different colour, which consequently have transverse vibrations of very different length and velocity, move through space with the same rapidity. The velocity of transmission and the refraction differ therefore in the interior of the different bodies through which the coloured rays pass.[54]

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[53] Fizeau gives his result in leagues, reckoning 25 (and consequently 4452 metres) to the equatorial degree. He estimates the velocity of light at 70000 such leagues, or about 210000 miles in the second. On the earlier experiments of Fizeau, see *Comptes rendus*, tom. xxix. p. 92. In Moigno, *Répert. d'Optique moderne*, P. iii. p. 1162, we find this velocity given at 70843 leagues (of 25=1°) or about 212529 miles, which approximates most nearly to the result of Bradley, as given by Busch.

[54] " D'après la théorie mathématique dans le système des ondes, les rayons de différentes couleurs, les rayons dont les ondulations sont inégales, doivent néanmoins se propager dans l'Ether avec la même vitesse. Il n'y a pas de différence à cet égard entre la propagation des ondes sonores, lesquelles se propagent dans l'air avec la même rapidité. Cette égalité de propagation des ondes sonores est bien établie expérimentalement par la similitude d'effet que produit une musique donnée à toutes distances du lieu où l'on l'exécute. La principale difficulté, je dirai l'unique difficulté, qu'on eût élevée contre le

For Arago's observations have shown that refraction in the prism is not altered by the relation of the velocity of light to that of the earth's motion. All the measurements coincide in the result, that the light of those stars towards which the earth is

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système des ondes, consistait donc à expliquer, comment la vitesse de propagation des rayons de différentes couleurs dans les corps différents pouvait être dissemblable et servir à rendre compte de l'inégalité de réfraction de ces rayons ou de la dispersion. On a montré récemment que cette difficulté n'est pas insurmontable; qu'on peut constituer l'Ether dans les corps inégalement denses de manière que des rayons à ondulations dissemblables s'y *propagent* avec des vitesses inégales: reste à déterminer, si les conceptions des géomètres à cet égard sont conformes à la nature des choses. Voici les amplitudes des ondulations déduites expérimentalement d'une série de faits relatif aux interfèrences:

| | mm |
|---|---|
| Violet . . . . . . | 0·000423 |
| Jaune . . . . . . . | 0·000551 |
| Rouge . . . . . . . | 0·000620 |

La vitesse de transmission des rayons de différentes couleurs dans les espaces célestes est la même dans le système des ondes et tout-à-fait indépendante de l'étendue ou de la vitesse des ondulations."

"According to the mathematical theory of a system of waves, rays of different colours, having unequal undulations, must nevertheless be transmitted through ether with the same velocity. There is no difference in this respect from the mode of propagation of waves of sound which are transmitted through the atmosphere with equal velocity. This equality of transmission in waves of sound may be well demonstrated experimentally by the uniformity of effect produced by music at all distances from the source whence it emanates. The principal, I may say the only objection, advanced against the undulatory theory, consisted in the difficulty of explaining how the velocity of the propagation of rays of different colours through different bodies could be dissimilar, while it accounted for the inequality of the refraction of the rays or of their dispersion. It has been recently shown that moving presents the same index of refraction as the light of those from which it is receding. Using the language of the emission hypothesis, this celebrated observer remarks, that bodies send forth rays of all velocities, but that among these different velocities one only is capable of exciting the sensation of light.[56]

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this difficulty is not insurmountable, and that the ether may be supposed to be transmitted through bodies of unequal density in such a manner that rays of dissimilar systems of waves may be propagated through it with unequal velocities; but it remains to be determined whether the views advanced by geometricians on this question are in unison with the actual nature of things. The following are the lengths of the undulations, as experimentally deduced from a series of facts in relation to interference:

| | mm |
|---|---|
| Violet . . . . . . . | 0·000423 |
| Yellow . . . . . . . | 0·000551 |
| Red . . . . . . . . | 0·000620 |

The velocity of the transmission of rays of different colours through celestial space, is equal in the system of waves, and is quite independent of the length or the velocity of the undulations." Arago, *MS. of* 1849. Compare also the *Annuaire pour* 1842, pp. 333-336. The length of the luminous wave of the ether, and the velocity of the vibrations, determine the character of the coloured rays. To the violet, which is the most refrangible ray, belong 662, while to the red, (or least refrangible ray with the greatest length of wave,) there belong 451 billions of vibrations in the second.

[55] "J'ai prouvé, il y a bien des années, par des observations directes que les rayons des étoiles vers lesquelles la Terre marche, et les rayons des étoiles dont la Terre s'éloigne, se réfractent exactement de la même quantité. Un tel résultat ne peut se concilier *avec la théorie de l'émission* qu'à l'aide d'une addition importante à faire à cette théorie: il faut admettre que les corps lumineux émettent des rayons de toutes les vitesses, et que les seuls rayons d'une vitesse déterminée sont visibles, qu'eux seuls produisent dans l'œil la sensation de lumière. Dans la théorie de l'émission, le rouge, le jaune, le vert, le bleu, le violet solaires sont respectivement accompag-

On comparing the velocities of solar, stellar, and terrestrial light, which are all equally refracted in the prism, with the velocity of the light of frictional electricity, we are disposed, in accordance with Wheatstone's ingeniously conducted experiments, to regard the lowest ratio in which the latter exceeds the former as 3:2. According to the lowest results of Wheatstone's optical rotatory apparatus, electric

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nés de rayons pareils, mais obscurs par défaut ou par excès de vitesse. A plus de vitesse correspond une moindre réfraction, comme moins de vitesse entraîne une réfraction plus grande. Ainsi chaque rayon rouge visible est accompagné de rayons obscurs de la même nature, qui se réfractent les uns plus, les autres moins que lui : ainsi *il existe des rayons dans les stries noires* de la portion rouge du spectre ; la même chose doit être admise des stries situées dans les portions jaunes, vertes, bleues et violettes."

"I showed many years ago, by direct observations, that the rays of those stars towards which the earth moves, and the rays of those stars from which it recedes, are repeated in exactly the same degree. Such a result cannot be reconciled with the *theory of emission*, unless we make the important admission that luminous bodies emit rays of all velocities, and that only rays of a determined velocity are visible, these alone being capable of impressing the eye with the sensation of light. In the theory of emission, the red, yellow, green, blue, and violet solar rays, are respectively accompanied by like rays, which are, however, dark from deficiency or excess of velocity. Excessive velocity is associated with a slight degree of refraction, while a smaller amount of velocity involves a slighter degree of refraction. Thus, every visible red ray is accompanied by dark rays of the same nature, of which some are more, and others less, refracted than the former; there are consequently *rays in the black lines* of the red portion of the spectrum; and the same must be admitted in reference to the lines situated in the yellow, green, blue, and violet portions." Arago, in the *Comptes rendus de l'Acad. des Sciences*, t. xvi. 1843, p. 404. Compare also t. viii. 1839, p. 326, and Poisson, *Traité de Mécanique*, ed. ii. 1833, t. i. § 168. According to the undulatory theory, the stars emit waves of extremely various transverse velocities of oscillations.

light traverses 288000 miles in a second.[68] If we reckon 189938 miles for stellar light, according to Struve's observations on aberration, we obtain the difference of 95776 miles as the greater velocity of electricity in one second.

These results are *apparently* opposed to the views advanced by Sir William Herschel, according to which solar and stellar light are regarded as the effects of an electro-magnetic process—a perpetual northern light. I say *apparently*, for no one will contest the possibility that there may be several very different magneto-electrical processes in the luminous cosmical bodies, in which light—the product of the process—may possess a different velocity of propagation. To this conjecture may be added the uncertainty of the numerical result yielded by the experiments of Wheatstone, who has himself admitted that they are not sufficiently established, but need further confirmation before they can be satisfactorily compared with the results deduced from observations on aberration and on the satellites.

The attention of physicists has been powerfully attracted to the experiments on the velocity of the transmission of electricity, recently conducted in the United States by Walker during the course of his electro-telegraphic determinations of the terrestrial longitudes of Washington, Philadelphia, New York, and Cambridge. According to Steinheil's description of these experiments, the astronomical clock of the Observatory at Philadelphia was brought to correspond so perfectly with Morse's writing apparatus on the telegraphic line, that this clock marked its own course by points on the endless paper fillets of the apparatus. The electric telegraph instantaneously conveys each of these clock times to the other stations, indicating to these the Philadelphia time by a succession of similar points on the advancing paper fillets. In this manner arbitrary signs, or the instant of a star's transit, may be similarly noted down at the station by a mere movement of the observer's finger on the stop. "The special advantage of the American method consists," as Steinheil observes, "in its rendering the determination of time independent of the combination of the two senses, sight and hearing, as the clock notes its own course, and indicates the instant of a star's transit (with a mean error, according to Walker's assertion, of only the 70th part of a second.) A constant difference between the compared clock times at Philadelphia and at Cambridge is dependent upon the time occupied by the electric current in twice traversing the closed circle between the two stations."

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[68] Wheatstone in the *Philos. Transact. of the Royal Soc. for* 1834, pp. 589, 591. From the experiments described in this paper it would appear that the human eye is capable of perceiving phenomena of light, whose duration is limited to the millionth part of a second (p. 591). On the hypothesis referred to in the text, of the supposed analogy between the light of the sun and polar light, see Sir John Herschel's *Results of Astron. Observ. at the Cape of Good Hope*, 1847, p. 351. Arago, in the *Comptes rendus pour* 1838, t. vii. p. 956, has referred to the ingenious application of Breguet's improved Wheatstone's rotatory apparatus for determining between the theories of emission and undulation, since, according to the former, light moves more rapidly through water than through air, while, according to the latter, it moves more rapidly through air than through water. (Compare also *Comptes rendus pour* 1850, t. xxx. pp. 489–495, 556.)

Eighteen equations of condition, from measurements made on conducting wires of 1050 miles, gave for the velocity of transmission of the hydro-galvanic current 18700 miles,[57] which is fifteen times less than that of the electric current in Wheatstone's rotatory discs. As in Walker's remarkable experiments *two wires* were not used, but half of the conduction, to use a conventional mode of expression, passed through the moist earth, we should seem to be justified in concluding that the velocity of the transmission of electricity depends upon the nature as well as the dimensions[58] of the medium. Bad conductors in the voltaic circuit become more powerfully heated than good conductors; and the experiments lately made by Riess[59] show that electric discharges are phenomena of a very various and complicated nature. The views prevailing at the present day regarding what is usually termed "connection through the earth" are opposed to the hypothesis of linear, molecular conduction between the extremities of the wires, and to the conjectures of the impediments to conduction, of accumulation, and disruption in a current; since what was formerly regarded as intermediate conduction in the earth is now conjectured to belong exclusively to an equalisation or restoration of the electric tension.

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[57] Steinheil in Schumacher's *Astr. Nachr.*, no. 679 (1849), s. 97–100; Walker *in the Proceedings of the American Philosophical Society*, vol. v. p. 128. (Compare earlier propositions of Pouillet in the *Comptes rendus*, t. xix. p. 1386.) The more recent ingenious experiments of Mitchel, Director of the Observatory at Cincinnati (Gould's *Astron. Journal*, Dec. 1849, p. 3, *On the velocity of the electric wave*), and the investigations of

Although it appears probable, from the extent of accuracy

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Fizeau and Gounelle at Paris, in April, 1850, differ both from Wheatstone's and Walker's results. The experiments recorded in the *Comptes rendus*, t. xxx. p. 439, exhibit striking differences between iron and copper as conducting media.

[58] See Poggendorff's *Annalen*, bd. lxxiii. 1848, s. 337, and Pouillet, *Comptes rendus*, t. xxx. p. 501.

[59] Riess, in *Poggend. Ann.*, bd. 78, s. 433. On the non-conduction of the intermediate earth see the important experiments of Guillemin *Sur le courant dans une pile isolée et sans communication entre les pôles* in the *Comptes rendus*, t. xxix. p. 521. "Quand on remplace un fil par la terre, dans les télégraphes electriques, la terre sert plutôt de reservoir commun, que de moyen d'union entre les deux extremités du fil." "When the earth is substituted for half the circuit in the electric telegraph, it serves rather as a common reservoir than as a means of connexion between the two extremities of the wire."

at present attainable in this kind of observation, that *the constant of aberration*, and consequently the velocity of light, is the same for all fixed stars, the question has frequently been mooted, whether it be not possible that there are luminous cosmical bodies, whose light does not reach us, in consequence of the particles of air being turned back by the force of gravitation exercised by the enormous masses of these bodies. The theory of emission gives a scientific form to these imaginative speculations.[60] I here only refer to such views because it will be necessary in the sequel that we should consider certain peculiarities of motion ascribed to Procyon, which appeared to indicate a disturbance from dark cosmical bodies. It is the object of the present portion of this work to notice the different directions to which scientific inquiry had inclined, at the period of its composition and publication, and thus to indicate the individual character of an epoch in the sidereal as well as the telluric sphere.

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[60] Mädler, *Astr.*, s. 380; also Laplace according to Moigno, *Répertoire d'Optique moderne*, 1847, t. i. p. 72. "Selon la théorie de l'émission on croit pouvoir démontrer que si le diamètre d'une étoile fixe serait 250 fois plus grand que celui du soleil, sa densité restant la même, l'attraction exercée à sa surface detruirait la quantité de mouvement, de la molécule lumineuse émise, de sorte qu'elle serait invisible à de grandes distances." "It seems demonstrable by the theory of emission that if the diameter of a fixed star be 250 times greater than that of the sun—its density remaining the same—the attraction exercised on the surface would destroy the amount of motion emitted from the luminous molecule; so that it would be invisible at great distances." If, with Sir William Herschel, we ascribe to Arcturus an apparent diameter of 0″·1, it follows that the true diameter of this star is only eleven times greater than that of our sun. (*Cosmos*, vol. i. p. 138.) From the above considerations on one of the causes of non-luminosity the velocity of light must be very different in cosmical bodies of different dimensions. This has, however, by no means been confirmed by the observations hitherto made. Arago says in the *Comptes rendus*, t. viii. p. 326, "Les expériences sur l'égale deviation prismatique des étoiles, vers lesquelles la terre marche ou dont elle s'éloigne, rend compte de l'égalité de vitesse apparente de toutes les étoiles." "Experiments made on the equal prismatic deviation of the stars towards which the earth is moving, and from which it is receding, explain the apparent equality of velocity in the rays of all the stars."

The *photometric* relations (relations of brightness) of the self-luminous bodies with which the regions of space are filled, have for more than two thousand years been an object of scientific observation and inquiry. The description of the starry firmanent did not only embrace determinations of places, the relative distances of luminous cosmical bodies from one another and from the circles depending on the apparent course of the sun and on the diurnal movement of the vault of heaven; but it also considered the relative intensity of the light of the stars. The earliest attention of mankind was undoubtedly directed to this latter point; individual stars having received names before they were arranged with others into groups and constellations. Among the wild tribes inhabiting the densely wooded regions of the Upper Orinoco and the Atabapo, where from the impenetrable nature of the vegetation I could only observe high culminating stars for determinations of latitude, I frequently found that certain individuals, more especially old men, had designations for Canopus, Achernar, the feet of the Centaur and $\alpha$ in the Southern Cross. If the catalogue of the constellations known as the *Catasterisms* of Eratosthenes, can lay claim to the great antiquity so long ascribed to it, (between Autolycus of Pitane and Timocharis, and therefore nearly a century and a half before the time of Hipparchus,) we possess in the astronomy of the Greeks a limit for the period when the fixed stars had not yet been arranged according to their relative magnitudes. In the emuneration of the stars belonging to each constellation, as given in the *Catasterisms*, frequent reference is made to the number of the largest and most luminous or of the dark and less easily recognized stars;[61] but we find no relative comparison of the stars contained in the different constellations. The *Catasterisms* are, according to Bernhardy, Baehr, and Letronne, more than two hundred years less ancient than the catalogue of Hipparchus, and are besides a careless compilation and a mere extract from the *Poeticum Astronomicum* (ascribed to Julius Hyginus), if not from the poem Ἑρμῆς of the older Eratosthenes. The catalogue of Hipparchus, which we possess in the form given to it in the Almagest, contains the earliest and most important determination of classes of magnitude (gradations of brightness) of 1022 stars, and therefore of about $\frac{1}{5}$th of all the stars in the firmament visible to the naked eye, and ranging from the 1st to the 6th magnitude inclusive. It remains undetermined whether these estimates are all due to Hipparchus, or whether they do not rather appertain in part to the observations of Timocharis or Aristyllus, which Hipparchus frequently used.

This work constituted the important basis on which was established the science of the Arabs and of the astronomers of the middle ages: the practice, transmitted to the nineteenth century, of limiting the number of stars of the first magnitude to 15 (although Mädler counts 18, and Rümker after a more careful observation of the southern celestial hemisphere upwards of 20) takes its origin from the classification of the Almagest, as given at the close of the table of stars in the eighth book. Ptolemy, referring to natural vision, called all stars dark which were fainter than those of his 6th class; and of this class, he singularly enough only instances

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[61] Eratosthenes, *Catasterismi*, ed. Schaubach, 1795, and *Eratosthenica*, ed. G. Bernhardy, 1822, p. 110–116. A distinction is made between stars λαμπροὺς (μεγάλους) and ἀμαυροὺς (cap. 2, 11, 41). Ptolemy also limits οἱ ἀμόρφωτοι to those stars which do not regularly belong to a constellation.

49 stars distributed almost equally over both hemispheres. Considering that the catalogue enumerates about one-fifth of all the fixed stars visible to the naked eye, it should, according to Argelander's investigations, have given 640 stars of the 6th magnitude. The nebulous stars (νεφελοειδεῖς) of Ptolemy and of the Pseudo-Eratosthenian *Catasterisms*, are mostly small stellar swarms,[62] appearing like nebulæ in the clearer atmosphere of the southern hemisphere. I more particularly base this conjecture on the mention of a nebula in the right hand of Perseus. Galileo, who, like the Greek and Arabian astronomers, was unacquainted with the nebula in Andromeda which is visible to the naked eye, says in his *Nuncius sidereus*, that *stellæ nebulosæ* are nothing more than stellar masses scattered in shining groups through the ether (*areolæ sparsim per æthera fulgent*).[63] The expression (τῶν μεγάλων τάξις), *the order of magnitudes*, although referring only to lustre, led, as early as the ninth century, to hypotheses on the diameters of stars of different brightness:[64] as if the intensity of light did not depend on the distance, volume, and mass, as also on the peculiar character of the surface of a cosmical body in more or less favouring the process of light.

At the period of the Mongolian supremacy, when, in the fifteenth century, astronomy flourished at Samarcand, under Timur Ulugh Beig, photometric determinations were facilitated by the subdivision of each of the six classes of Hipparchus and Ptolemy into three subordinate groups; distinctions, for example, being drawn between the *small*, *intermediate*, and

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[62] *Ptol. Almag.* ed. Halma, tom. ii. p. 40, and in *Eratosth. Catust.*, cap. 22, p. 18. ἡ δέ κεφαλὴ καὶ ἡ ἅρπη ἄναπτος ὁρᾶται, διὰ δέ νεφελώδους συστροφῆς δοκεῖ τισιν ὁρᾶσθαι. Thus, too, Geminus, *Phæn.* (ed. Hilder, 1590), p. 46.

[63] *Cosmos*, vol. ii. pp. 713–14.

[64] Muhamedis Alfragani Chronologica et Ast. Elementa, 1590, cap. xxiv. p. 118.

*large* stars of the second magnitude—an attempt which reminds us of the decimal gradations of Struve and Argelander.[65] This advance in photometry, by a more exact determination of degrees of intensity, is ascribed in Ulugh Beig's tables to Abdurrahman Sufi, who wrote a work "on the knowledge of the fixed stars," and was the first who mentions one of the Magellanic clouds under the name of the White Ox. Since the discovery and gradual improvement of telescopic vision, these estimates of the gradations of light have been extended far below the sixth class. The desire of comparing the increase and decrease of light in the newly appeared stars in Cygnus and Ophiuchus (the former of which continued luminous for twenty-one years), with the brightness of other stars, called attention to photometric determinations. The so-called *dark* stars of Ptolemy, which were below the 6th magnitude, received numerical designations according to the relative intensity of their light. "Magnitudes, from the 8th down to the 16th," says Sir John Herschel, "are familiar to those who are in the practice of using powerful instruments."[66] But at this faint degree of brightness, the denominations for the different gradations in the scale of magnitudes are very undetermined, for Struve occasionally classes, among the 12th or 13th, stars which Sir John Herschel designates as belonging to the 18th or 20th magnitudes.

The present is not a fitting place to discuss the merits of the very different methods which have been adopted for the measurement of light within the last hundred-and-fifty years, from Auzout and Huygens to Bouguer and Lambert; and from Sir William Herschel, Rumford, and Wollaston, to

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[65] Some MSS. of the Almagest refer to such subdivisions or intermediate classes, as they add the words *μείζων* or *ελάσσων* to the determination of magnitudes. (Cod. Paris, no. 2389.) Tycho expressed this increase or diminution by points.

[66] Sir John Herschel, *Outlines of Astr.*, pp. 520–27.

Steinheil and Sir John Herschel. It will be sufficient for the object of this work briefly to indicate the different methods. These were a comparison of the shadows of artificial lights, differing in numbers and distance; diaphragms; plane glasses of different thickness and colour; artificial stars formed by reflection on glass spheres; the juxta-position of two seven-feet telescopes, separated by a distance which the observer could pass in about a second; reflecting instruments in which two stars can be simultaneously seen and compared, when the telescope has been so adjusted that the star directly observed gives two images of like intensity;[67] an apparatus having, (in front of the object-glass,) a mirror and diaphragms, whose rotation is measured on a ring; telescopes with divided object-glasses, on either half of which the stellar light is received through a prism; astrometers[63] in which a prism reflects the

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[67] This is the application of reflecting sextants to the determination of the intensity of stellar light; of this instrument I made greater use when in the tropics than of the diaphragms recommended to me by Borda. I began my investigation under the clear skies of Cumana, and continued them subsequently till 1803, but under less favourable conditions, on the elevated plateaux of the Andes, and on the coasts of the Pacific, near Guayaquil. I had formed an arbitrary scale in which I marked Sirius, as the brightest of all the fixed stars, equal to 100; the stars of the first magnitude between 100 and 80, those of the second magnitude between 80 and 60, of the third between 60 and 45, of the fourth between 45 and 30, and those of the fifth between 30 and 20. I especially measured the constellations of Argo and Grus, in which I thought I had observed alterations since the time of Lacaille. It seemed to me after a careful combination of magnitudes, using other stars as intermediate gradations, that Sirius was as much brighter than Canopus, as $\alpha$ Centauri than Achernar. My numbers cannot, on account of the above mentioned mode of classification, be compared directly with those which Sir John Herschel made public as early as 1838. (See my *Recueil d'Observ. astr.*, vol. i. p. lxxi., and *Relat. hist. du Voyage aux Régions équin.*, t. i. pp. 518 and 624; also *Lettre de M. de Humboldt à M. Schumacher en Fevr.* 1839, in the *Astr. Nachr.*, no. 374.) In this letter I wrote as follows: "M. Arago, qui possède des moyens photométriques entièrement différents de ceux qui ont été publiés jusqu'ici, m'avait rassuré sur la partie des erreurs qui pouvaient provenir du

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changement d'inclinaison d'un miroir entamé sur la face intérieure. Il blâme d'ailleurs le principe de ma méthode et le regarde comme peu susceptible de perfectionnement, non seulement à cause de la différence des angles entre l'étoile vue directement et celle qui est amenée par réflexion, mais surtout parceque le résultat de la mesure d'intensité dépend de la partie de l'œil qui se trouve en face de l'oculaire. Il y a erreur lorsque la pupille n'est pas très exactement à la hauteur de la limite inférieure de la portion non entamée du petit miroir." "M. Arago, who possesses photometric data, differing entirely from those hitherto published, had instructed me in reference to those errors which might arise from a change of inclination of a mirror silvered on its inner surface. He moreover blames the principle of my method, and regards it as little susceptible of correctness, not only on account of the difference of angles between the star seen directly and by reflection; but especially because the result of the amount of intensity depends on the part of the eye opposite to the ocular glass. There will be an error in the observations when the pupil is not exactly adjusted to the elevation of the lower limit of the unplated part of the small mirror."

[63] Compare Steinheil, *Elemente der Helligkeits-Messungen am Sternenhimmel*, *München* 1836, (*Schum. Astr. Nachr.* no. 609,) and Sir J. Herschel, *Results of Astronomical Observations made during the years* 1834–1838 *at the Cape of Good Hope* (Lond. 1847), pp. 353–357. Seidel attempted in 1846 to determine by means of Steinheil's photometer the quantities of light of several stars of the first magnitude, which attain the requisite degree of latitude in our northern latitudes. Assuming Vega to be = 1, he finds for Sirius 5·13; for Rigel, whose lustre appears to be on the increase, 1·30; for Arcturus 0·84; for Capella 0·83; for Procyon 0·71; for Spica 0·49; for Atair 0·40; for Aldebaran 0·36; for Deneb 0·35; for Regulus 0·34; for Pollux 0·30; he does not give the intensity of the light of Betelgeuze, on account of its being a variable star, as was particularly manifested between 1836 and 1839. (*Outlines*, p. 523.)

image of the moon or of Jupiter, and concentrates it through a lens at different distances into a star more or less bright. Sir John Herschel, who has been more zealously engaged than any other astronomer of modern times in making numerical determinations in both hemispheres of the intensity of light, confesses that the practical application of exact photometric methods must still be regarded as a "desideratum in astronomy," and that "photometry is yet in its infancy." The increasing interest taken in variable stars, and the recent celestial phenomenon of the extraordinary increase of light exhibited in the year 1837 in a star of the constellation Argo, has made astronomers more sensible of the importance of obtaining certain determinations of light.

It is essential to distinguish between the mere arrangement of stars according to their lustre, without numerical estimates of the intensity of light (an arrangement adopted by Sir John Herschel in his *Manual of Scientific Enquiry prepared for the use of the Navy*), and classifications in which intensity of light is expressed by numbers, under the form of so-called relations of magnitude, or by more hazardous estimates of the quantities of radiated light.[69] The first numerical scale, based on estimates calculated with the naked eye, but improved by an ingenious elaboration of the materials[70] probably deserves the preference over any other approximative method practicable in the present imperfect condition of photometrical instruments, however much the exactness of the estimates must be endangered by the varying powers of individual observers—the serenity of the atmosphere—the different altitudes of widely distant stars, which can only be compared by means of numerous intermediate stellar bodies—and above all by the unequal colour of the light. Very brilliant stars of the 1st magnitude, such as Sirius and Canopus, α Centauri and Achernar, Deneb and Vega, on account of their white light, admit far less readily of comparison by the naked eye than fainter stars below the 6th and 7th magnitudes. Such a comparison is even more difficult when we attempt to contrast yellow stars of intense light, like Procyon, Capella, or Atair, with red ones, like Aldebaran, Arcturus, and Betelgeux.[71]

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[69] Compare for the numerical data of the photometric results 4 tables of Sir John Herschel's *Astr. Obs. at the Cape*, a) p. 341; b) pp. 367–371; c) p. 440; and d) in his *Outlines of Astr.*, pp. 522–525, 645–646. For a mere arrangement without numbers see the *Manual of Scientific Enquiry prepared for the use of the Navy*, 1849, p. 12. In order to improve the old conventional mode of classing the stars according to magnitudes, a scale of photometric magnitudes consisting in the addition of 0·41, as explained more in detail in *Astr. Obs. at the Cape*, p. 370, has been added to the vulgar scale of magnitudes in the *Outlines of Astronomy*, p. 645, and these scales are subjoined to this portion of the present work, together with a list of northern and southern stars.

Sir John Herschel has endeavoured to determine the relation between the intensity of solar light, and that of a star of the 1st magnitude by a photometric comparison of the moon with the double-star α Centauri of the southern hemisphere, which is the third in brightness of all the stars. He thus fulfilled (as had been already done by Wollaston) a wish expressed by John Michell[72] as early as 1767. Sir John Herschel found from the mean of eleven measurements conducted with a prismatic apparatus; that the full moon was 27408 times brighter than α Centauri. According to Wollaston the light of the sun is 801072 times brighter than the full moon;[73] whence it follows that the light transmitted to us from the sun is to the light which we receive from $\alpha$ Centauri as 22000 millions to 1. It seems therefore very probable, when, in accordance with its parallax, we take into account the distance of the star, that its (absolute) proper luminosity exceeds that of our sun by $2\frac{3}{10}$ times. Wollaston found the brightness of Sirius 20000 million times fainter than that of the sun. From what we at present believe to be the parallax of Sirius ($0''\cdot230$) its actual (absolute) intensity of light exceeds that of the sun 63 times.[74] Our sun therefore belongs, in reference to the intensity of its process of light, to the fainter fixed stars. Sir John Herschel estimates the intensity of the light of Sirius to be equal to the light of nearly two hundred stars of the 6th magnitude. Since it is very probable, from analogy with the experiments already made, that all cosmical bodies are subject to variations both in their movements through space and in the intensity of their light, although such variations may occur at very long and undetermined periods, it is obvious, considering the dependence of all organic life on the sun's temperature and on the intensity of its light, that the perfection of photometry constitutes a great and important subject for scientific inquiry. Such an improved condition of our knowledge can render it alone possible to transmit to future generations numerical determinations of the photometric condition of the firmament. By these means we shall be enabled to explain numerous geognostic phenomena relating to the *thermal history of our atmosphere*, and to the earlier distribution of plants and animals. Such considerations did not escape the inquiring mind of William Herschel, who, more than half a century ago, before the close connection between electricity and magnetism had been discovered, compared the ever luminous cloud-envelopes of the sun's body with the polar light of our own terrestrial planet.[75]

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[70] Argelander, *Durchmusterung des nördl. Himmels zwischen* 45° *und* 80° *Decl.* 1846, s. xxiv.–xxvi.; Sir John Herschel, *Astr. Observ. at the Cape of Good Hope*, pp. 327 340, 365.

[71] *Op. cit.*, p. 304, and *Outl.*, p. 522.

[72] *Philos. Transact.*, vol. lvii. for the year 1767, p. 234.

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[73] Wollaston, in the *Philos. Transact.* for 1829, p. 27. Herschel's *Outlines*, p. 553. Wollaston's comparison of the light of the sun with that of the moon was made in 1799, and was based on observations of the shadows thrown by lighted wax tapers, while in the experiments made on Sirius in 1826 and 1827, images reflected from thermometer bulbs were employed. The earlier data of the intensity of the sun's light, compared with that of the moon, differ widely from the results here given. They were deduced by Michelo and Euler, from theoretical grounds at 450000 and 374000, and by Bouguer, from measurements of the shadows of the light of wax tapers, at only 300000. Lambert assumes Venus, in her greatest intensity of light, to be 3000 times fainter than the full moon. According to Steinheil, the sun must be 3286500 times further removed from the earth than it is, in order to appear, like Arcturus, to the inhabitants of our planet (Struve, *Stellarum Compositarum Mensuræ Micrometricæ*, p. clxiii.); and according to Sir John Herschel the light of Arcturus exhibits only half the intensity of Canopus; (Herschel, *Observ. at the Cape*, p. 34.) All these conditions of intensity, more especially the important comparison of the brightness of the sun, the full moon, and of the ash-coloured light of our satellite which varies so greatly according to the different positions of the earth considered as a reflecting body, deserve further and serious investigation.

[74] *Outl. of Astr.*, p. 553; *Astr. Observ. at the Cape*, p. 363.

Arago has ascertained that the most certain method for the direct measurement of the intensity of light consists in observing the complementary condition of the coloured rings seen by transmission and reflection. I subjoin in a note,[76] in his own words,

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[75] William Herschel *On the nature of the sun and fixed stars* in the *Philos. Transact. for* 1795, p. 62; and *On the changes that happen to the fixed stars* in the *Philos. Transact. for* 1796, p. 186. Compare also Sir John Herschel, *Observ. at the Cape*, pp. 350–352.

[76] *Extract of a Letter from M. Arago to M. de Humboldt, May*, 1850.

*Mesures photométriques.*

"Il n'existe pas de Photomètre proprement dit, c'est-à-dire the results of my friend's photometric method, to which he has added an account of the optical principle on which his cyanometer is based.

The so-called relations of the magnitude of the fixed stars, as

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d'instrument donnant l'intensité d'une lumière isolée; le Photomètre de Leslie, à l'aide duquel il avait eu l'audace de vouloir comparer la lumière de la lune à la lumière du soleil, par des actions calorifiques, est complètement défectueux. J'ai prouvé, en effet, que ce prétendu Photomètre monte quand on l'expose à la lumière du soleil, qu'il descend sous l'action de la lumière du feu ordinaire, et qu'il reste complètement stationnaire lorsqu'il reçoit la lumière d'une lampe d'Argand. Tout ce qu'on a pu faire jusqu'ici, c'est de comparer entr'elles deux lumières en présence, et cette comparaison n'est même à l'abri de toute objection que lorsqu'on ramène ces deux lumières à l'égalité par un affaiblissement graduel de la lumière la plus forte. C'est comme criterium de cette égalité que j'ai employé les anneaux colorés. Si on place l'une sur l'autre deux lentilles d'un long foyer, il se forme autour de leur point de contact des anneaux colorés tant par voie de réflexion que par voie de transmission. Les anneaux réfléchis sont complémentaires en couleur des anneaux transmis; ces deux séries d'anneaux se neutralisent mutuellement quand les deux lumières qui les forment et qui arrivent simultanément sur les deux lentilles, sont égales entr'elles.

" Dans le cas contraire on voit des traces ou d'anneaux réfléchis ou d'anneaux transmis, suivant que la lumière qui forme les premiers, est plus forte ou plus foible que la lumière à laquelle on doit les seconds. C'est dans ce sens seulement que les anneaux colorés jouent un rôle dans les mesures de la lumière auxquelles je me suis livré."

(*b.*) *Cyanomètre.*

" Mon cyanomètre est une extension de mon polariscope. Ce dernier instrument, comme tu sais, se compose d'un tube fermé à l'une de ses extrémités par une plaque de cristal de roche perpendiculaire à l'axe, de 5 millimètres d'épaisseur; et d'un prisme doué de la double réfraction, placé du côté de l'œil. Parmi les couleurs variées que donne cet appareil, lorsque de la lumière polarisée le traverse, et qu'on fait tourner

given in our catalogues and maps of the stars, sometimes indicate as of simultaneous occurrence that which belongs to very different periods of cosmical alterations of light. The order of the letters which, since the beginning of the seventeenth

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le prisme sur lui-même, se trouve par un heureux hasard la nuance du bleu de ciel. Cette couleur bleue fort affaiblie, c'est-à-dire très mélangée de blanc lorsque la lumière est presque neutre, augmente d'intensité—progressivement, à mesure que les rayons qui pénètrent dans l'instrument, renferment une plus grande proportion de rayons polarisés.

"Supposons donc que le polariscope soit dirigé sur une feuille de papier blanc; qu'entre cette feuille et la lame de cristal de roche il existe une pile de plaques de verre susceptible de changer d'inclinaison, ce qui rendra la lumière éclairante du papier plus ou moins polarisée; la couleur bleue fournie par l'instrument va en augmentant avec l'inclinaison de la pile, et l'on s'arrête lorsque cette couleur paraît la même que celle de la région de l'atmosphère dont on veut déterminer la teinte cyanométrique, et qu'on regarde à l'œil nu immédiatement à côté de l'instrument. La mesure de cette teinte est donnée par l'inclinaison de la pile. Si cette dernière partie de l'instrument se compose du même nombre de plaques et d'une même espèce de verre, les observations faites dans divers lieux seront parfaitement comparables entr'elles."

(*a.*) *Photometric Measurements.*

"There does not exist a photometer properly so called, that is to say, no instrument giving the intensity of an isolated light; for Leslie's photometer, by means of which he boldly supposed that he could compare the light of the moon with that of the sun, by their caloric actions, is utterly defective. I found, in fact, that this pretended photometer rose on being exposed to the light of the sun, that it fell when exposed to a moderate fire, and that it remained altogether stationary when brought near the light of an Argand lamp. All that has hitherto been done has been to compare two lights when contiguous to one another, but even this comparison cannot be relied on unless the two lights be equalized, the stronger being gradually reduced to the intensity of the feebler. For the purpose of judging of this inequality I employed coloured rings. On century. have been added to the stars in the generally consulted *Uranometria Bayeri*, are not, as was long supposed, certain indications of these alterations of light. Argelander has ably shown, that the relative brightness of the stars cannot

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placing on one another two lenses of a great focal length, coloured rings will be formed round their point of contact as much by means of reflection as of transmission. The colours of the reflected rings are complementary to those of the transmitted rings; these two series of rings neutralise one another when the two lights by which they are formed and which fall simultaneously on the two lenses are equal.

"In the contrary case, we meet with traces of reflected or transmitted rings, according as the light by which the former are produced, is stronger or fainter than that from which the latter are formed. It is only in this manner that coloured rings can be said to come into play in those photometric measurements to which I have directed my attention."

(*b.*) *Cyanometer.*

"My cyanometer is an extension of my polariscope. This latter instrument, as you know, consists of a tube closed at one end by a plate of rock crystal, cut perpendicular to its axis, and 5 millimètres in thickness; and of a double refracting prism placed near the part to which the eye is applied. Among the varied colours yielded by this apparatus, when it is traversed by polarised light and the prism turns on itself, we fortunately find a shade of azure. This blue, which is very faint. that is to say mixed with a large quantity of white when the light is almost neutral, gradually increases in intensity in proportion to the quantity of polarised rays which enter the instrument.

"Let us suppose the polariscope directed towards a sheet of white paper; and that between this paper and the plate of rock crystal there is a pile of glass plates capable of being variously inclined, by which means the illuminating light of the paper would be more or less polarised; the blue colour yielded by the instrument will go on increasing with the inclination of the pile; and the process must be continued until the colour appears of the same intensity with the region of the atmosphere whose cyanometrical tinge is to be deterbe inferred from the alphabetical order of the letters, and that Bayer was influenced in his choice of these letters, by the form and direction of the constellations.[77]

## PHOTOMETRIC ARRANGEMENT OF THE FIXED STARS.

I close this section with a table taken from Sir John Herschel's *Outlines of Astronomy*, pp. 645 and 646. I am indebted for the mode of its arrangement, and for the following lucid exposition, to my learned friend Dr. Galle, from whose communication, addressed to me, in March, 1850, I extract the subjoined observations:—

"The numbers of the photometric scale in the *Outlines of Astronomy* have been obtained by adding throughout 0·41 to the results calculated from the vulgar scale. Sir John Herschel arrived at these more exact determinations by observing their "sequences" of brightness, and by combining these observations with the average ordinary data of magnitudes, especially on those given in the catalogue of the Astronomical Society for the year 1827. (See *Observ. at the Cape*, pp. 304–352.) The actual photometric measurements of several stars as obtained by the Astrometer (*op. cit.* p. 353), have not been directly employed in this catalogue, but have only served generally to show the relation existing between the ordinary scale (of 1st, 2nd, 3rd, &c., magnitudes) to the actual photometric quantities of individual stars. This comparison has given the singular result that our ordinary stellar magnitudes (1, 2, 3...) decrease in about the same ratio as a star of the 1st magnitude when removed to the distances of 1, 2, 3...

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mined, and which is seen by the naked eye in the immediate vicinity of the instrument. The amount of this colour is given by the inclination of the pile; and if this portion of the apparatus consist of the same number of plates formed of the same kind of glass, observations made at different places may readily be compared together."

[77] Argelander *de fide Uranometriæ Bayeri*, 1842, pp. 14–23. "In eadem classe littera prior majorem splendorem nullo modo indicat" (§ 9). Bayer did not therefore show that the light of Castor was more intense in 1603 than that of Pollux.

by which its brightness, according to photometric law, would attain the values $1, \frac{1}{4}, \frac{1}{9}, \frac{1}{16}$th . . . (*Observ. at the Cape*, pp. 371, 372; *Outlines*, pp. 521, 522); in order, however, to make this accordance still greater, it is only necessary to raise our previously adopted stellar magnitudes about half a magnitude (or more accurately considered 0·41) so that a star of the 2·00 magnitude would in future be called 2·41, and star of 2·50 would become 2·91, and so forth. Sir John Herschel therefore proposes that this "photometric" (raised) scale shall in future be adopted (*Observ. at the Cape*, p. 372, and *Outlines*, p. 522)—a proposition in which we cannot fail to concur. For while on the one hand the difference from the vulgar scale would hardly be felt (*Observ. at the Cape*, p. 372); the table in the *Outlines* (p. 645) may, on the other hand, serve as a basis for stars down to the fourth magnitude. The determinations of the magnitudes of the stars according to the rule, that the brightness of the stars of the 1st, 2nd, 3rd, 4th magnitude is exactly as $1, \frac{1}{4}, \frac{1}{9}, \frac{1}{16}$ . . . as is now shown approximatively, is therefore already practicable. Sir John Herschel employs $\alpha$ Centauri as the standard star of the first magnitude, for his *photometric scale*, and as the unit for the quantity of light (*Outlines*, p. 523; *Observ. at the Cape*, p. 372). If therefore we take the square of a star's photometric magnitude, we obtain the inverse ratio of the quantity of its light to that of $\alpha$ Centauri. Thus for instance if $\kappa$ Orionis have a photometric magnitude of 3, it consequently has $\frac{1}{9}$ of the light of $\alpha$ Centauri. The number 3 would at the same time indicate that $\kappa$ Orionis is 3 times more distant from us than $\alpha$ Centauri, provided both stars be bodies of equal magnitude and brightness. If another star, as for instance Sirius, which is four times as bright, were chosen as the unit of the photometric magnitudes indicating distances, the above conformity to law would not be so simple and easy of recognition. It is also worthy of notice that the distance of $\alpha$ Centauri has been ascertained with some probability, and that this distance is the smallest of any yet determined. Sir John Herschel demonstrates (*Outlines*, p. 521,) the inferiority of other scales to the photometric, which progresses in order of the squares, $1, \frac{1}{4}, \frac{1}{9}, \frac{1}{16}$ . . . He likewise treats of geometric progressions, as for instance, $1, \frac{1}{2}, \frac{1}{4}, \frac{1}{8}$, . . . or $1, \frac{1}{3}, \frac{1}{9}, \frac{1}{27}$ . . . . The gradations employed by yourself in your observations under the equator, during your travels in America, are arranged in a kind of arithmetical progression (*Recueil d'Observ. Astron.*, vol. i. p. lxxi., and Schumacher's *Astron. Nachr.* no. 374). These scales however correspond less closely than the photometric scale of progression (by squares) with the vulgar scale. In the following table the 190 stars have been given from the *Outlines*, without reference to their declination, whether southern or northern, being arranged solely in accordance with their magnitudes."

List of 190 stars from the 1st to the 3rd magnitude, arranged according to the determinations of Sir John Herschel, giving the ordinary magnitudes with greater accuracy, and likewise the magnitudes in accordance with his proposed photometric classification:—

### STARS OF THE FIRST MAGNITUDE.

| Star. | Magnitude. | | Star. | Magnitude. | |
|---|---|---|---|---|---|
| | Vulg. | Phot. | | Vulg. | Phot. |
| Sirius | 0·08 | 0·49 | α Orionis | 1·0 : | 1·43 |
| η Argus (Var.) | — | — | α Eridani | 1·09 | 1·50 |
| Canopus | 0·29 | 0·70 | Aldebaran | 1·1 : | 1·5 : |
| α Centauri | 0·59 | 1·00 | β Centauri | 1·17 | 1·58 |
| Arcturus | 0·77 | 1·18 | α Crucis | 1·2 | 1·6 |
| Rigel | 0·82 | 1·23 | Antares | 1·2 | 1·6 |
| Capella | 1·0 : | 1·4 : | α Aquilæ | 1·28 | 1·69 |
| α Lyræ | 1·0 : | 1·4 : | Spica | 1·38 | 1·79 |
| Procyon | 1·0 : | 1·4 : | | | |

### STARS OF THE SECOND MAGNITUDE.

| Star. | Magnitude. | | Star. | Magnitude. | |
|---|---|---|---|---|---|
| | Vulg. | Phot. | | Vulg. | Phot. |
| Fomalhaut | 1·54 | 1·95 | λ Scorpii | 1·87 | 2·28 |
| β Crucis | 1·57 | 1·98 | α Cygni | 1·90 | 2·31 |
| Pollux | 1·6 : | 2·0 : | Castor | 1·94 | 2·35 |
| Regulus | 1·6 : | 2·0 : | ε Ursæ (Var.) | 1·95 | 2·36 |
| α Gruis | 1·66 | 2·07 | α Ursæ (Var.) | 1·96 | 2·37 |
| γ Crucis | 1·73 | 2·14 | ζ Orionis | 2·01 | 2·42 |
| ε Orionis | 1·84 | 2·25 | β Argus | 2·03 | 2·44 |
| ε Canis | 1·86 | 2·27 | α Persei | 2·07 | 2·48 |

## Stars of the Second Magnitude—*continued.*

| Star. | Magnitude. | | Star. | Magnitude. | |
|---|---|---|---|---|---|
| | Vulg. | Phot. | | Vulg. | Phot. |
| γ Argus ............ | 2·08 | 2·49 | γ Leonis............ | 2·34 | 2·75 |
| ε Argus ............ | 2·18 | 2·59 | β Gruis ............ | 2·36 | 2·77 |
| η Ursæ (Var.) ... | 2·18 | 2·59 | α Arietis ......... | 2·40 | 2·81 |
| γ Orionis ......... | 2·18 | 2·59 | σ Sagittarii ...... | 2·41 | 2·82 |
| α Triang austr. ... | 2·23 | 2·64 | δ Argus .... ...... | 2·42 | 2·83 |
| ε Sagittarii ...... | 2·26 | 2·67 | ζ Ursæ ............ | 2·43 | 2·84 |
| β Tauri ............ | 2·28 | 2·69 | β Andromedæ ... | 2·45 | 2·86 |
| Polaris ......... | 2·28 | 2·69 | β Ceti................ | 2·46 | 2·87 |
| θ Scorpii ......... | 2·29 | 2·70 | λ Argus............ | 2·46 | 2·87 |
| α Hydræ ......... | 2·30 | 2·71 | β Aurigæ ......... | 2·48 | 2·89 |
| δ Canis ............ | 2·32 | 2·73 | γ Andromedæ ... | 2·50 | 2·91 |
| α Pavonis ......... | 2·33 | 2·74 | | | |

## Stars of the Third Magnitude.

| Star. | Magnitude. | | Star. | Magnitude. | |
|---|---|---|---|---|---|
| | Vulg. | Phot. | | Vulg. | Phot. |
| γ Cassiopeiæ ...... | 2·52 | 2·93 | ι Argus ........... | 2·80 | 3·21 |
| α Andromedæ .... | 2·54 | 2·95 | ε Bootis ............ | 2·80 | 3·21 |
| θ Centauri ......... | 2·54 | 2·95 | α Lupi ............ | 2·82 | 3·23 |
| α Cassiopeiæ ...... | 2·57 | 2·98 | ε Centauri ......... | 2·82 | 3·23 |
| β Canis ............ | 2·58 | 2·99 | η Canis ............ | 2·85 | 3·26 |
| κ Orionis............ | 2·59 | 3·00 | β Aquarii ......... | 2·85 | 3·26 |
| γ Geminorum ...... | 2·59 | 3·00 | δ Scorpii............ | 2·86 | 3·27 |
| δ Orionis............ | 2·61 | 3·02 | ε Cygni ............ | 2·88 | 3·29 |
| Algol (Var.) .. | 2·62 | 3·03 | η Ophiuchi......... | 2·89 | 3·30 |
| ε Pegasi ............ | 2·62 | 3·03 | γ Corvi ............ | 2·90 | 3·31 |
| γ Draconis ......... | 2·62 | 3·03 | α Cephei............ | 2·90 | 3·31 |
| β Leonis ............ | 2·63 | 3·04 | δ Centauri ......... | 2·91 | 3·32 |
| α Ophiuchi ......... | 2·63 | 3·04 | α Serpentis ...... | 2·92 | 3·33 |
| β Cassiopeiæ ...... | 2·63 | 3·04 | δ Leonis............ | 2·94 | 3·35 |
| γ Cygni ............ | 2·63 | 3·04 | κ Argus ............ | 2·94 | 3·35 |
| α Pegasi ............ | 2·65 | 3·06 | β Corvi ............ | 2·95 | 3·36 |
| β Pegasi ............ | 2·65 | 3·06 | β Scorpii ......... | 2·96 | 3·37 |
| γ Centauri ......... | 2·68 | 3·09 | ζ Centauri ......... | 2·96 | 3·37 |
| α Coronæ............ | 2·69 | 3·10 | ζ Ophiuchi......... | 2·97 | 3·38 |
| γ Ursæ ............ | 2·71 | 3·12 | α Aquarii ......... | 2·97 | 3·38 |
| ε Scorpii ............ | 2·71 | 3·12 | π Argus ............ | 2·98 | 3·39 |
| ζ Argus .. ......... | 2·72 | 3·13 | γ Aquilæ ......... | 2·98 | 3·39 |
| β Ursæ .. ........ | 2·77 | 3·18 | δ Cassiopeiæ ...... | 2·99 | 3·40 |
| α Phœnicis ......... | 2·78 | 3·19 | δ Centauri ......... | 2·99 | 3·40 |

## STARS OF THE THIRD MAGNITUDE—*continued.*

| Star. | Magnitude. | | Star. | Magnitude. | |
|---|---|---|---|---|---|
| | Vulg. | Phot. | | Vulg. | Phot |
| α Leporis | 3·00 | 3·41 | γ Persei | 3·34 | 3·75 |
| δ Ophiuchi | 3·00 | 3·41 | μ Ursæ | 3 35 | 3 76 |
| ζ Sagittarii | 3·01 | 3·42 | β Triang. bor. | 3 35 | 3·76 |
| η Bootis | 3·01 | 3·42 | π Scorpii | 3·35 | 3·76 |
| η Draconis | 3·02 | 3 43 | β Leporis | 3·35 | 3·76 |
| π Ophiuchi | 3·05 | 3·46 | γ Lupi | 3·36 | 3·77 |
| β Draconis | 3 06 | 3·47 | δ Persei | 3 36 | 3·77 |
| β Libræ | 3·07 | 3·48 | ψ Ursæ | 3·36 | 3·77 |
| γ Virginis | 3·08 | 3·49 | ε Aurigæ (Var.) | 3·37 | 3·78 |
| μ Argus | 3·08 | 3·49 | υ Scorpii | 3·37 | 3·78 |
| β Arietis | 3·09 | 3·50 | ι Orionis | 3·37 | 3·78 |
| γ Pegasi | 3·11 | 3·52 | γ Lyncis | 3·39 | 3·80 |
| δ Sagittarii | 3·11 | 3·52 | ζ Draconis | 3·40 | 3·81 |
| α Libræ | 3·12 | 3·53 | α Aræ | 3·40 | 3·81 |
| λ Sagittarii | 3·13 | 3·54 | π Sagittarii | 3·40 | 3·81 |
| β Lupi | 3·14 | 3·55 | π Herculis | 3·41 | 3·82 |
| ε Virginis? | 3·14 | 3·55 | β Can. min.? | 3·41 | 3·82 |
| α Columbæ | 3·15 | 3·56 | ζ Tauri | 3·42 | 3·83 |
| ϑ Aurigæ | 3·17 | 3·58 | δ Draconis | 3·42 | 3·83 |
| β Herculis | 3·18 | 3·59 | μ Geminorum | 3·42 | 3·83 |
| ι Centauri | 3·20 | 3·61 | γ Bootis | 3·43 | 3·84 |
| δ Capricorni | 3·20 | 3·61 | ε Geminorum | 3·43 | 3·84 |
| δ Corvi | 3·22 | 3·63 | α Muscæ | 3·43 | 3·84 |
| α Can. ven. | 3·22 | 3·63 | α Hydri? | 3·44 | 3·85 |
| β Ophiuchi | 3·23 | 3·64 | τ Scorpii | 3·44 | 3·85 |
| δ Cygni | 3·24 | 3·65 | δ Herculis | 3·44 | 3·85 |
| ε Persei | 3·26 | 3·67 | δ Geminorum | 3·44 | 3·85 |
| η Tauri? | 3·26 | 3·67 | ρ Orionis | 3·45 | 3·86 |
| β Eridani | 3 26 | 3·67 | β Cephei | 3·45 | 3·86 |
| ϑ Argus | 3·26 | 3·67 | ϑ Ursæ | 3·45 | 3·86 |
| β Hydri | 3·27 | 3·68 | ζ Hydræ | 3·45 | 3·86 |
| ζ Persei | 3·27 | 3·68 | γ Hydræ | 3·46 | 3·87 |
| ζ Herculis | 3·28 | 3·69 | β Triang. austr. | 3·46 | 3·87 |
| ε Corvi | 3·28 | 3·69 | ι Ursæ | 3·46 | 3·87 |
| ι Aurigæ | 3·29 | 3·70 | η Aurigæ | 3·46 | 3·87 |
| γ Urs. min. | 3·30 | 3·71 | γ Lyræ | 3·47 | 3·88 |
| η Pegasi | 3·31 | 3·72 | η Geminorum | 3·48 | 3·89 |
| β Aræ | 3·31 | 3·72 | γ Cephei | 3·48 | 3·89 |
| α Toucani | 3·32 | 3·73 | κ Ursæ | 3·49 | 3·90 |
| β Capricorni | 3 32 | 3·73 | ε Cassiopeiæ | 3·49 | 3·90 |
| ρ Argus | 3 32 | 3·73 | ϑ Aquilæ | 3 50 | 3·91 |
| ζ Aquilæ | 3·32 | 3·73 | σ Scorpii | 3·50 | 3·91 |
| β Cygni | 3 33 | 3 74 | τ Argus | 3·50 | 3 91 |

"The following short table of the photometric quantities of 17 stars of the 1st magnitude (as obtained from the photometric scale of magnitudes) may not be devoid of interest:"

| | |
|---|---|
| Sirius | 4·165 |
| η Argus | — |
| Canopus | 2·041 |
| α Centauri | 1·000 |
| Arcturus | 0·718 |
| Rigel | 0·661 |
| Capella | 0·510 |
| α Lyrae | 0·510 |
| Procyon | 0·510 |
| α Orionis | 0·489 |
| α Eridani | 0·444 |
| Aldebaran | 0·444 |
| β Centauri | 0·401 |
| α Crucis | 0·391 |
| Antares | 0·391 |
| α Aquilæ | 0·350 |
| Spica | 0·312 |

"The following is the photometric quantity of stars strictly belonging to the 1, 2................6 magnitudes in which the quantity of the light of α Centauri is regarded as the unit:"

| Magnitude on the vulgar scale. | Quantity of Light. |
|---|---|
| 1·00 | 0·500 |
| 2·00 | 0·172 |
| 3·00 | 0·086 |
| 4·00 | 0·051 |
| 5·00 | 0·034 |
| 6·00 | 0·024 |

# III.

## NUMBER, DISTRIBUTION, AND COLOUR OF THE FIXED STARS. — STELLAR MASSES (STELLAR SWARMS). — THE MILKY WAY INTERSPERSED WITH A FEW NEBULOUS SPOTS.

We have already, in the first section of this fragmentary Astrognosy, drawn attention to a question first mooted by Olbers.[1] If the entire vault of heaven were covered with innumerable strata of stars, one behind the other, as with a wide-spread starry canopy, and light were undiminished in its passage through space, the sun would be distinguishable only by its spots, the moon would appear as a dark disc, and amid the general blaze not a single constellation would be visible. During my sojourn in the Peruvian plains, between the shores of the Pacific and the chain of the Andes, I was vividly reminded of a state of the heavens, which, though diametrically opposite in its cause to the one above referred to, constitutes an equally formidable obstacle to human knowledge. A thick mist obscures the firmament in this region for a period of many months, during the season, called *el tiempo de la garua.* Not a planet, not the most brilliant stars of the southern hemisphere, neither Canopus, the southern Cross, nor the feet of the Centaur, are visible. It is frequently almost impossible to distinguish the position of the moon. If by chance the outline of the sun's disc be visible during the day it appears devoid of rays, as if seen through coloured glasses, being generally of a yellowish red, sometimes of a white, and occasionally even of a bluish green colour. The mariner, driven onwards by the cold south currents of the sea, is unable to recognize the shores, and in the absence of all observations of latitude sails past the harbours which he desired to enter. A dipping needle alone could, as I have elsewhere shown, save him from this error, by the local direction of the magnetic curves.[2]

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[1] *Vide supra*, p. 46 and note.

Bouguer and his coadjutor, Don Jorge Juan, complained, long before me, of the "unastronomical sky of Peru." A graver consideration associates itself with this stratum of vapours in which there is neither thunder nor lightning, in consequence of its incapacity for the transmission of light or electric charges, and above which the Cordilleras, free and cloudless, raise their elevated plateaux and snow-covered summits. According to what modern geology has taught us to conjecture regarding the ancient history of our atmosphere, its primitive condition, in respect to its mixture and density, must have been unfavourable to the transmission of light. When we consider the numerous processes which in the primary world may have led to the separation of the solids, fluids, and gases around the earth's surface, the thought involuntarily arises how narrowly the human race escaped being surrounded with an untransparent atmosphere, which though perhaps not greatly prejudicial to some classes of vegetation, would yet have completely veiled the whole of the starry canopy. All knowledge of the structure of the universe would thus have been withheld from the inquiring spirit of man. Excepting our own globe, and perhaps the sun and the moon, nothing would have appeared to us to have been created. An isolated triad of stars—the sun, the moon, and the earth—would have appeared the sole occupants of space. Deprived of a great, and indeed of the sublimest portion of his ideas of the Cosmos, man would have been left without all those incitements which, for thousands of years, have incessantly impelled him to the solution of important problems, and have exercised so beneficial an influence on the most brilliant progress made in the higher spheres of mathematical development of thought. Before we enter upon an enumeration of what has already been achieved, let us dwell for a moment on the danger from which the spiritual development of our race has escaped, and the physical impediments which would have formed an impassable barrier to our progress.

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[2] *Cosmos*, vol. i. p. 171 and note.

In considering the number of cosmical bodies which fill the celestial regions, three questions present themselves to our notice. How many fixed stars are visible to the naked eye? How many of these have been gradually catalogued, and their places determined according to longitude and latitude, or according to their right ascension and declination? What is the number of stars from the 1st to the 9th and 10th magnitudes, which have been seen in the heavens by means of the telescope? These three questions may, from the materials of observation at present in our possession, be determined at least approximatively. Mere conjectures based on the gauging of the stars in certain portions of the Milky Way, differ from the preceding questions, and refer to the theoretical solution of the question: How many stars might be distinguished throughout the whole heavens with Herschel's twenty-feet telescope, including the stellar light "which is supposed to require 2000 years to reach our earth?"[3]

The numerical data which I here publish in reference to this subject, are chiefly obtained from the final results of my esteemed friend Argelander, director of the Observatory at Bonn. I have requested the author of the *Durchmusterung*

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[3] On the space-penetrating power of telescopes, see Sir John Herschel, *Outlines of Astr.*, § 803.

*des nördlichen Himmels* (*Survey of the Northern Heavens*) to submit the previous results of Star-catalogues to a new and careful examination. In the lowest class of stars visible to the naked eye, much uncertainty arises from organic difference in individual observations; stars between the 6th and 7th magnitude being frequently confounded with those strictly belonging to the former class. We obtain, by numerous combinations, from 5000 to 5800, as the mean number of the stars throughout the whole heavens visible to the unaided eye. Argelander[4] determines the distribution of the fixed stars according to difference of magnitude, down to the 9th, in about the following proportion,—

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[4] I cannot attempt to include in a note *all* the grounds on which Argelander's views are based. It will suffice if I extract the following remarks from his own letters to me: "Some years since (1843,) you recommended Captain Schwink to estimate from his Mappa Cœlestis, the total number of stars from the 1st to the 7th magnitude inclusive, which the heavens appeared to contain; his calculations give 12148 stars for the space between 30° south and 90° north declination; and consequently, if we conjecture that the proportion of stars is the same from 30° S. D. to the South Pole, we should have 16200 stars of the above-named magnitudes throughout the whole firmament. This estimate seems to me to approximate very nearly to the truth. It is well known, that on considering the whole mass, we find each class contains about three times as many stars as the one preceding. (Struve, *Catalogus Stellarum duplicium*, p. xxxiv; Argelander, *Bonner Zonen*, s. xxvi.) I have given in my *Uranometria*, 1441 stars of the 6th magnitude, north of the equator, whence we should obtain about 3000 for the whole heavens; this estimate does not, however include the stars of the 6·7 mag., which would be reckoned among those of the 6th, if only entire classes were admitted into the calculation. I think the number of the last-named stars might be assumed at 1000, according to the above rule, which would give 4000 stars for the 6th, and 12000 for the 7th, or 18000 for the 1st to the 7th inclusive. From other considerations on the number of the stars of the 7th magnitude, as given in my zones,—namely 2257, (p. xxvi.) and allowing for those which have been twice or oftener observed, and for those

| 1st Mag. | 2nd Mag. | 3rd Mag. | 4th Mag. | 5th Mag. |
|---|---|---|---|---|
| 20 | 65 | 190 | 425 | 1100 |

| 6th Mag. | 7th Mag. | 8th Mag. | 9th Mag. |
|---|---|---|---|
| 3200 | 13000 | 40000 | 142000 |

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which have probably been overlooked, I approximated somewhat more nearly to the truth. By this method, I found 2340 stars of the 7th magnitude, between 45° and 80° N. D.; and therefore, nearly 17000 for the whole heavens. Struve, in his *Description de l'Observatoire de Poulkova*, p. 268, gives 13400 for the number of stars down to the 7th magnitude, in the region of the heavens explored by him (from — 15° to + 90°), whence we should obtain 21300 for the whole firmament. According to the Introduction to Weisse's *Catal. e Zonis Regiomontanis*, *ded.* p. xxxii. Struve found in the zone extending from — 15° to + 15° by the calculus of probabilities, 3903 stars from the 1st to the 7th, and therefore 15050 for the entire heavens. This number is lower than mine, because Bessel estimated the brighter stars nearly half a magnitude lower than I did. We can here only arrive at a mean result, which would be about 18000 from the 1st to the 7th magnitudes inclusive. Sir John Herschel, in the passage of the *Outlines of Astronomy*, p. 521, to which you allude, speaks only of "the whole number of stars *already registered*, down to the seventh magnitude inclusive, amounting to from 12000 to 15000." As regards the fainter stars, Struve finds within the above-named zone, (from — 15° to + 15°) for the faint stars of the 8th magnitude, 10557, for those of the 9th, 37739, and consequently, 40800 stars of the 8th, and 145800 of the 9th magnitude for the whole heavens. Hence, according to Struve, we have from the 1st to the 9th magnitude inclusive, 15100 + 40800 + 145800 = 201700 stars. He obtained these numbers by a careful comparison of those zones or parts of zones, which comprise the same regions of the heavens, deducing by the calculus of probabilities the number of stars actually present from the numbers of those common to, or different, in each zone. As the calculation was made from a very large number of stars, it is deserving of great

The number of stars distinctly visible to the naked eye (amounting in the horizon of Berlin to 4022, and in that of

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confidence. Bessel has enumerated about 61000 different stars from the 1st to the 9th inclusive, in his collective zones between — 15° and + 45°, after deducting such stars as have been repeatedly observed, together with those of the 9·10 magnitude; whence we may conclude, after taking into account such as have probably been overlooked, that this portion of the heavens contains about 101500 stars of the above-named magnitudes. My zones between + 45° and + 80°, contain about 22000 stars, (*Durchmusterung des nördl. Himmels*, s. xxv.) which would leave about 19000, after deducting 3000 for those belonging to the 9·10 magnitude. My zones are somewhat richer than Bessel's, and I do not think we can fairly assume a larger number than 2850, for the stars actually existing between their limits (+ 45° and + 80°); whence we should obtain 130000 stars to the 9th magnitude inclusive, between — 15° and + 80°. This space is, however, only 0·62181 of the whole heavens, and we therefore obtain 209000 stars for the entire number, supposing an equal distribution to obtain throughout the whole firmament; these numbers again closely approximate to Struve's estimate, and indeed, not improbably exceed it to a considerable extent, since Struve reckoned stars of the 9·10 magnitude among those of the 9th. The numbers which, according to my view, may be assumed for the whole firmament, are therefore as follows: 1st mag., 20; 2nd, 65; 3rd, 190; 4th, 425; 5th, 1100; 6th, 3200; 7th, 13000; 8th, 40000; 9th, 142000; and 200000 for the entire number of stars from the 1st to the 9th magnitude inclusive.

If you would contend that Lalande (*Hist. céleste*, p. iv.) has given the number of stars observed by himself with the naked eye at 6000, I would simply remark that this estimate contains very many that have been repeatedly observed, and that after deducting these, we obtain only about 3800 stars for the portion of the heavens between—26° 30′ and + 90° observed by Lalande. As this space is 0·72310 of the whole heavens, we should again have for this zone 5255 stars visible

Alexandria to 4638,) appears at first sight strikingly small.[6] If we assume the moon's mean semi-diameter at 15′ 33″·5, it would require 195,291 surfaces of the full moon to cover the whole heavens. If we further assume that the stars are uniformly distributed, and reckon in round numbers 200000 stars from the 1st to the 9th magnitude, we shall have nearly a single star for each full-moon surface. This result explains why, also, at any given latitude, the moon does not

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to the naked eye. An examination of Bode's Uranography (containing 17240 stars), which is composed of the most heterogeneous elements, does not give more than 5600 stars from the 1st to the 6th magnitude inclusive, after deducting the nebulous spots and smaller stars as well as those of the 6·7th magnitude, which have been raised to the 6th. A similar estimate of the stars registered by La Caille between the south pole and the tropic of Capricorn, and varying from the 1st to the 6th magnitude, presents for the whole heavens two limits of 3960 and 5900, and thus confirms the mean result already given by yourself. You will perceive that I have endeavoured to fulfil your wish for a more thorough investigation of these numbers, and I may further observe that M. Heis of Aix-la-Chapelle has for many years been engaged in a very careful revision of my *Uranometrie*. From the portions of this work already complete, and from the great additions made to it by an observer gifted with keener sight than myself, I find 2836 stars from the 1st to the 6th magnitude inclusive for the northern hemisphere, and therefore, on the pre-supposition of equal distribution, 5672 as the number of stars visible throughout the whole firmament to the keenest unaided vision." (*From the MSS. of Prof. Argelander*, March, 1850.)

[6] Schubert reckons the number of stars, from the 1st to the 6th magnitude, at 7000 for the whole heavens (which closely approximates to the calculation made by myself in *Cosmos*, vol. i. p. 140,) and upwards of 5000 for the horizon of Paris. He gives 70000 for the whole sphere, including stars of the 9th magnitude. (*Astronomie*, th. iii. s. 54.) These numbers are all much too high. Argelander finds only 58000 from the 1st to the 8th magnitude.

more frequently conceal stars visible to the naked eye. If the calculation of occultations of the stars were extended to those of the 9th magnitude, a stellar eclipse would, according to Galle, occur on an average every 44′ 30″, for in this period the moon traverses a portion of the heavens equal in extent to its own surface. It is singular that Pliny, who was undoubtedly acquainted with Hipparchus's catalogue of stars, and who comments on his boldness in attempting as it were "to leave heaven as a heritage to posterity," should have enumerated only 1600 stars visible in the fine sky of Italy![6] In this enumeration he had, however, descended to stars of the 5th, whilst half a century later Ptolemy indicated only 1025 stars down to the 6th magnitude.

Since it has ceased to be the custom to class the fixed stars merely according to the constellations to which they belong, and they have been catalogued according to determinations of place, that is, in their relations to the great circles of the equator or the ecliptic, the extension as well as the accuracy of star catalogues has advanced with the progress of science and the improved construction of instruments. No catalogues of the stars compiled by Timocharis and Aristyllus (283, B.C.) have reached us; but although, as Hipparchus remarks in the fragment "on the length of the year," cited in the seventh book of the Almagest (cap. 3, p. xv. Halma,) their observations were conducted in a very rough manner (*πάνυ ὁλοσχερῶς*) there can be no doubt that they both determined the declination of many stars, and that these determinations preceded, by nearly a century and a half, the table of fixed stars compiled by Hipparchus. This astronomer is said to have been incited by the phenomenon of a new star to attempt a survey of the whole firmament, and endeavour to determine the position of the stars; but the truth of this statement rests solely on Pliny's testimony, and has often been regarded as the mere echo of a subsequently invented tradition.[7] It does indeed seem remarkable that Ptolemy should not refer to the circumstance, but yet it must be admitted that the sudden appearance of a brightly luminous star in Cassiopeia (November, 1572,) led Tycho Brahe to compose his catalogue of the stars. According to an ingenious conjecture of Sir John Herschel,[8] the star referred to by Pliny may have been the new star which appeared in Scorpio in the month of July of the year 134 before our era, (as we learn from the Chinese Annals of the reign of Wou-ti, of the Han dynasty.) Its appearance occurred exactly six years before the epoch at which, according to Ideler's investigations, Hipparchus compiled his catalogue of the stars. Edward Biot, whose early death proved so great a loss to science, found a record of this celestial phenomenon in the celebrated collection of Ma-tuan-lin, which contains an account of all the comets and remarkable stars observed between the years B.C. 613, and A.D. 1222.

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[6] "Patrocinatur vastitas cœli, immensa discreta altitudine, in duo atque septuaginta signa. Hæc sunt rerum et animantium effigies, in quas digessere cœlum periti. In his quidem mille sexcentas adnotavere stellas, insignes videlicet effectu visuve" . . . . Plin., ii. 41.—"Hipparchus nunquam satis laudatus, ut quo nemo magis approbaverit cognationem cum homine siderum animasque nostras partem esse cœli, novam stellam et aliam in ævo suo genitam deprehendit, ejusque motu, qua die fulsit, ad dubitationem est adductus, anne hoc sæpius fieret moverenturque et eæ quas putamus affixas; itemque ausus rem etiam Deo improbam, adnumerare posteris stellas ac sidera ad nomen expungere, organis excogitatis, per quæ singularum loca atque magnitudines signaret, ut facile discerni posset ex eo, non modo an obirent nascerenturve, sed an omnino aliqua transirent moverenturve, item an crescerent minuerenturque, cœlo in hereditate cunctis relicto, si quisquam qui cretionem eam caperet inventus esset." Plin., ii. 26.

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[7] Delambre, *Hist. de l'Astr. anc.*, tom. i. p. 290, and *Hist. de l' Astr. mod.*, tom. ii. p. 186.

[8] *Outlines*, § 831; Edward Biot *sur les Etoiles Extraordinaires observées en Chine*, in the *Connaissance des temps pour* 1846.

The tripartite didactic poem of Aratus,[9] to whom we are indebted for the only remnant of the works of Hipparchus that has come down to us, was composed about the period of Eratosthenes, Timocharis, and Aristyllus. The astronomical non-meteorological portion of the poem is based on the uranography of Eudoxus of Cnidos. The catalogue compiled by Hipparchus is unfortunately not extant; but, according to Ideler,[10] it probably constituted the principal part of his work, cited by Suidas, "On the arrangement of the region of the fixed stars and the celestial bodies," and contained 1080 determinations of position for the year B.C. 128. In Hipparchus's other Commentary on Aratus the positions of the stars, which are determined more by equatorial armillæ than by the astrolabe, are referred to the equator by right ascension and declination; while in Ptolemy's catalogue of stars, which is supposed to have been entirely copied from that of Hipparchus, and which gives 1025 stars, together with five so-called nebulæ, they are referred by longitudes and latitudes to the ecliptic.[11] On comparing the number of fixed stars in the Hipparcho-Ptolemaic Catalogue, *Almagest*, ed. Halma, t. ii. p. 83, (namely, for the 1st mag., 15 stars; 2nd, 45; 3rd, 208; 4th, 474; 5th, 217; 6th, 49,) with the numbers of Argelander as already given, we find, as might be expected, a great paucity of stars of the 5th and 6th magnitudes, and also an extraordinarily large number of those belonging to the 3rd and 4th. The vagueness in the determinations of the intensity of light in ancient and modern times renders direct comparisons of magnitude extremely uncertain.

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[9] It is worthy of remark that Aratus was mentioned with approbation almost simultaneously by Ovid (*Amor.*, i. 15,) and by the Apostle Paul, at Athens, in an earnest discourse directed against the Epicureans and Stoics. Paul (*Acts*, ch. xvii. v. 28), although he does not mention Aratus by name, undoubtedly refers to a verse composed by him (*Phæn.*, v. 5) on the close communion of mortals with the Deity.

[10] Ideler, *Untersuchungen über den Ursprung der Sternnamen*, s. xxx.–xxxv. Baily in the *Mem. of the Astron. Soc.*, vol. xiii. 1843, pp. 12 and 15, also treats of the years according to our era, to which we must refer the observations of Aristyllus, as well as the catalogues of the stars compiled by Hipparchus (128, and not 140, B.C.) and by Ptolemy (138 A.D.).

[11] Compare Delambre, *Hist. de l'Astr. anc.*, tom. i. p. 184; tom. ii. p. 260. The assertion, that Hipparchus, in addition to the right ascension and declination of the stars, also indi-

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cated their positions in his catalogue, according to longitude and latitude, as was done by Ptolemy, is wholly devoid of probability and in direct variance with the *Almagest*, book vii. cap. 4, where this reference to the ecliptic is noticed as something new, by which the knowledge of the motions of the fixed stars round the pole of the ecliptic may be facilitated. The table of stars with the longitudes attached, which Petrus Victorius found in a Medicean Codex and published with the life of Aratus at Florence in 1567, is indeed ascribed by him to Hipparchus, but without any proof. It appears to be a mere rescript of Ptolemy's catalogue from an old manuscript of the Almagest, and does not give the latitudes. As Ptolemy was imperfectly acquainted with the amount of the retrogression of the equinoctial and solstitial points (*Almag.*, vii. c. 2, p. 13, Halma), and assumed it about $\frac{28}{100}$ too slow, the catalogue which he determined for the beginning of the reign of Antoninus (Ideler, *op. cit.* s. xxxiv.) indicates the positions of the stars at a much earlier epoch (for the year 63 A.D.) (Regarding the improvements for reducing stars to the time of Hipparchus, see the observations and tables as given by Encke in Schumacher's *Astron. Nachr.*, no. 608, s. 113–126.) The earlier epoch to which Ptolemy unconsciously reduced the stars in his catalogue, corresponds tolerably well with the period to which we may refer the Pseudo-Eratosthenian Catasterisms, which, as I have already elsewhere observed, are more recent than the time of Hyginus, who lived in the Augustine age, but appear to be taken from him and have no connection with the poem of Hermes by the true Eratosthenes. (*Eratosthenica*, ed. Bernhardy, 1822, pp. 114, 116, 129.) These Pseudo-Eratosthenian Catasterisms contain, moreover, scarcely 700 individual stars distributed among the mythical constellations.

Although the so-called Ptolemaic catalogue of the fixed stars enumerated only one-fourth of those visible to the naked eye at Rhodes and Alexandria, and, owing to erroneous reductions of the precession of the equinoxes, determined their positions as if they had been observed in the year 63 of our era; yet, throughout the sixteen hundred years immediately following this period, we have only three original catalogues of stars, perfect for their time; that of Ulugh Beg (1437), that of Tycho Brahe (1600), and that of Hevelius (1660). During the short intervals of repose which, amid tumultuous revolutions and devastations of war, occurred between the ninth and fifteenth centuries, practical astronomy, under Arabs, Persians, and Moguls (from Al-Mamun, the son of the great Harun Al-Raschid, to the Timurite, Mohammed Taraghi Ulugh Beg, the son of Shah Rokh) attained an eminence till then unknown. The astronomical tables of Ebn-Junis (1007), called the *Hakemitic* tables, in honour of the Fatimite Calif, Aziz Ben-Hakem Biamrilla, afford evidence, as do also the *Ilkhanic* tables[12] of Nassir-Eddin Tusi (who founded the great observatory at Meragha, near Tauris, 1259), of the advanced knowledge of the planetary motions,—the improved condition of measuring instruments, and the multiplication of more accurate methods differing from those employed by Ptolemy. In addition to clepsydras,* pendulum-oscillations[13] were already at this period employed in the measurement of time.

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[12] *Cosmos*, vol. ii. pp. 594–5. The Paris Library contains a manuscript of the Ilkhanic Tables by the hand of the son of Nassir-Eddin. They derive their name from the title "Ilkhan," assumed by the Tartar princes who held rule in Persia. Reinaud, *Introd. de la Géogr. d'Aboulféda*, 1848, p. cxxxix.

* For an account of clepsydras, see *Beckmann's Inventions*, vol. i. 341, *et seq.* (Bohn's edition.)—*Ed.*

[13] Sédillot fils, *Prolégomènes des Tables Astr. d'Oloug-Bey*, 1847, p. cxxxiv. note 2. Delambre, *Hist. de l'Astr. du moyen âge*, p. 8.

The Arabs had the great merit of showing how tables might be gradually amended by a comparison with observations. Ulugh Beg's catalogue of the stars, originally written in Persian, was entirely completed from original observations made in the Gymnasium at Samarcand, with the exception of a portion of the southern stars enumerated by Ptolemy,[14] and not visible in 39° 52′ lat. (?) It contains only 1019 positions of stars, which are reduced to the year 1437. A subsequent commentary gives 300 other stars, observed by Abu-Bekri Altizini in 1533. Thus we pass from Arabs, Persians, and Moguls, to the great epoch of Copernicus, and nearly to that of Tycho Brahe.

The extension of navigation in the tropical seas, and in high southern latitudes, has, since the beginning of the sixteenth century, exerted a powerful influence on the gradual extension of our knowledge of the firmament, though in a less degree than that effected a century later by the application of the telescope. Both were the means of revealing new and unknown regions of space. I have already in other works considered[15] the reports circulated first by Americus Vespucius, then by Magellan, and Pigafetta (the companion of Magellan and Elcano), concerning the splendour of the southern sky; and the descriptions given by Vicente Yañez, Pinzon, and Acosta, of the black patches (Coal Sacks), and by Anghiera and Andrea Corsali of the Magellanic clouds. A merely sensuous contemplation of the aspect of the heavens here also preceded measuring astronomy. The richness of the firmament near the southern pole, which, as is well known, is on the contrary peculiarly deficient in stars, was so much exaggerated that the intelligent Polyhistor Cardanus indicated in this region 10000 bright stars which were said to have been seen by Vespucius with the naked eye.[16]

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[14] In my investigations on the relative value of astronomical determinations of position in Central Asia (*Asie centrale*, t. iii. pp. 581–596), I have given the latitudes of Samarcand and Bokhara according to the different Arabic and Persian MSS. contained in the Paris Library. I have shown that the former is probably more than 39° 52′, whilst most of the best manuscripts of Ulugh Beg give 39° 37′, and the *Kitab al-athual* of Alfares, and the *Kanum* of Albyruni give 40°. I would again draw attention to the importance, in a geographical no less than an astronomical point of view, of determining the longitude and latitude of Samarcand by new and trustworthy observations. Burnes's Travels have made us acquainted with the latitude of Bokhara, as obtained from observations of culmination of stars; which gave 39° 43′ 41″. There is therefore only an error of from 7 to 8 minutes in the two fine Persian and Arabic MSS. (Nos. 164 and 2460) of the Paris Library. Major Rennell, whose combinations are generally so successful, made an error of about 19′ in determining the latitude of Bokhara. (Humboldt, *Asie centrale*, t. iii. p. 592, and Sédillot in the *Prolégomènes d'Oloug-Beg*, pp. cxxiii.–cxxv.)

Friedrich Houtman and Petrus Theodori of Embden (who, according to Olbers, is the same person as Dircksz Keyser) now first appeared as zealous observers. They measured distances of stars at Java and Sumatra; and at this period the most southern stars were first marked upon the celestial maps of Bartsch, Hondius, and Bayer, and by Kepler's industry were inserted in Tycho Brahe's Rudolphine tables.

Scarcely half a century had elapsed from the time of Magellan's circumnavigation of the globe before Tycho commenced his admirable observations on the positions of the fixed stars, which far exceeded in exactness all that had hitherto been done in practical astronomy, not excepting even the laborious observations of the Landgrave William IV. at Cassel. Tycho Brahe's catalogue, as revised and published by Kepler, contains no more than 1000 stars, of which one-fourth at most belong to the sixth magnitude. This catalogue, and that of Hevelius, which was less frequently employed, and contained 1564 determinations of position for the year 1660, were the last which were made by the unaided eye, owing their compilation in this manner to the capricious disinclination of the Dantzig astronomer to apply the telescope to purposes of measurement.

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[15]. *Cosmos*, pp. 664–8; Humboldt, *Examen crit. de l'Histoire de la Géogr.*, t. iv. pp. 321–336; t. v. pp. 226–238.

[16] *Cardani Paralipomenon*, lib. viii. cap. 10. (*Opp.*, t. ix. ed. Lugd. 1663, p. 508.)

This combination of the telescope with measuring instruments—the union of telescopic vision and measurements—at length enabled astronomers to determine the position of stars below the sixth magnitude, and more especially between the seventh and the twelfth. The region of the fixed stars might now for the first time be said to be brought within the reach of observers. Enumerations of the fainter telescopic stars, and determinations of their position, have not only yielded the advantage of making a larger portion of the regions of space known to us by the extension of the sphere of observation, but they have also (what is still more important) indirectly exercised an essential influence on our knowledge of the structure and configuration of the universe, on the discovery of new planets, and on the more rapid determination of their orbits. When William Herschel conceived the happy idea of as it were casting a sounding line in the depths of space, and of counting during his gaugings the stars which passed through the field of his great telescope,[17] at different distances from the Milky Way, the law was discovered that the number of stars increased in proportion to their vicinity to the Milky Way—a law which gave rise to the idea of the existence of large concentric rings filled with millions of stars which constitute the many-cleft Galaxy. The knowledge of the number and the relative position of the faintest stars facilitates (as was proved by Galle's rapid and felicitous discovery of Neptune, and by that of several of the smaller planets) the recognition of planetary cosmical bodies which change their positions, moving as it were between fixed boundaries. Another circumstance proves even more distinctly the importance of very complete catalogues of the stars. If a new planet be once discovered in the vault of heaven, its notification in an older catalogue of positions will materially facilitate the difficult calculation of its orbit. The indication of a new star which has subsequently been lost sight of, frequently affords us more assistance than, considering the slowness of its motion, we can hope to gain by the most careful measurements of its course through many successive years. Thus the star numbered 964 in the catalogue of Tobias Mayer has proved of great importance for the determination of Uranus, and the star numbered 26266 in Lalande's catalogue[18] for that of Neptune. Uranus, before it was recognized as a planet, had, as is now well known, been observed twenty-one times; once, as already stated, by Tobias Mayer, seven times by Flamstead, once by Bradley, and twelve times by Le Monnier. It may be said that our increasing hope of future discoveries of planetary bodies rests partly on the perfection of our telescopes (Hebe, at the time of its discovery in July, 1847, was a star of the 8·9 magnitude, while in May, 1849, it was only of the 11th magnitude), and partly, and perhaps more, on the completeness of our star-catalogues, and on the exactness of our observers.

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[17] *Cosmos*, vol. i. pp. 71–73.

The first catalogue of the stars which appeared after the epoch when Morin and Gascoigne taught us to combine telescopes with measuring instruments, was that of the southern stars compiled by Halley. It was the result of a short residence at St. Helena in the years 1677 and 1678, but, singularly enough, does not contain any determinations below the 6th magnitude.[19] Flamstead had, indeed, begun his great Star Atlas at an earlier period; but the work of this celebrated observer did not appear till 1712. It was succeeded by Bradley's observations (from 1750 to 1762), which led to the discovery of aberration and nutation, and have been rendered celebrated by the *Fundamenta Astronomiæ* of our countryman Bessel (1818),[20] and by the stellar catalogues of La Caille, Tobias Mayer, Cagnoli, Piazzi, Zach, Pond, Taylor, Groombridge, Argelander, Airy, Brisbane, and Rümker.

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[18] Baily, *Cat. of those stars in the "Histoire Céleste" of Jerome de Lalande, for which tables of reduction to the epoch* 1800 *have been published by Prof. Schumacher*, 1847, p. 1195. On what we owe to the perfection of star catalogues see the remarks of Sir John Herschel in *Cat. of the British Assoc.*, 1845, p. 4, § 10. Compare also, on stars that have disappeared, Schumacher, *Astr. Nachr.*, no. 624, and Bode, *Jahrb. für* 1817, s. 249

We here only allude to those works which enumerate a great and important part[21] of the stars of the 7th to the 10th magnitude which occupy the realms of space. The catalogue known under the name of Jerome de Lalande's, but which is, however, solely based on observations made by his nephew, François de Lalande, and by Burckhardt between the years 1789 and 1800, has only recently been duly appreciated. After having been carefully revised by Francis Baily, under the direction of the "British Association for the Advancement of Science," (in 1847,) it now contains 47390 stars, many of which are of the 9th and some even below that magnitude. Harding, the discoverer of Juno, catalogued above 50000 stars in twenty-seven maps. Bessel's great work on the exploration of the celestial zones, which comprises 75000 observations (made in the years 1825–1833 between — 15° and + 45° declination) has been continued from 1841 to 1844 with the most praiseworthy care, as far as + 80° decl., by Argelander at Bonn. Weisse of Cracow, under the auspices of the Academy of St. Petersburgh, has reduced 31895 stars for the year 1825, (of which 19738 belonged to the 9th magnitude) from Bessel's zones, between — 15° and + 15° decl.;[22] and Argelander's exploration of the northern heavens from + 45° to + 80° decl. contains about 22000 well determined positions of stars.

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[19] *Memoirs of the Royal Astron. Soc.*, vol. xiii. 1843, pp. 33 and 168.

[20] Bessel, *Fundamenta Astronomiæ pro anno* 1755, *deducta ex observationibus viri incomparabilis James Bradley in Specula astronomica Grenovicensi*, 1818. Compare also Bessel, *Tabulæ Regiomontanæ reductionum observationum astronomicarum ab anno* 1750 *usque ad annum* 1850 *computatæ* (1830).

[21] I here compress into a note the numerical data taken from star catalogues, containing lesser masses and a smaller number of positions, with the names of the observers, and the number of positions attached:—La Caille, in scarcely ten months, during the years 1751 and 1752, with instruments magnifying only eight times, observed 9766 southern stars, to the 7th magnitude inclusive, which were reduced to the year 1750 by Henderson; Tobias Mayer, 998 stars to 1756; Flamstead, originally only 2866, to which 564 were added by Baily's care; (*Mem. of the Astr. Soc.*, vol. iv. pp. 1291–64); Bradley, 3222, reduced by Bessel to the year 1755; Pond, 1112; Piazzi, 7646 to 1800; Groombridge, 4243, mostly circumpolar stars, to 1810; Sir Thomas Brisbane, and Rümker, 7385 stars, observed in New Holland, in the years 1822–1828; Airy, 2156 stars, reduced to the year 1845; Rümker, 12000 on the Hamburg horizon; Argelander

I cannot, I think, make more honourable mention of the great work of the star maps of the Berlin Academy, than by quoting the words used by Encke, in reference to this undertaking, in his oration to the memory of Bessel:—"With the completeness of catalogues is connected the hope that

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(Cat. of Abo,) 560; Taylor, (Madras,) 11015. The British Association Catalogue of Stars, (1845,) drawn up under Baily's superintendence, contains 8377 stars from the 1st to 7½ magnitudes. For the southern stars we have the rich catalogues of Henderson, Fallows, Maclear, and Johnson at St. Helena.

[22] Weisse, *Positiones mediæ stellarum fixarum in Zonis Regiomontanis a Besselio inter* — 15° *et* + 15° *decl. observatarum ad annum* 1825 *reductæ*, (1846); with an important Preface by Struve.

by a careful comparison of the different aspects of the heavens with those stars which have been noted as fixed points, we may be enabled to discover all moving celestial bodies, whose change of position can scarcely, owing to the faintness of their light, be noted by the unaided eye, and that we may in this manner complete our knowledge of the solar system. While Harding's admirable atlas gives a perfect representation of the starry heavens—as far as Lalande's *Histoire Céleste*, on which it is founded, was capable of affording such a picture—Bessel, in 1824, after the completion of the first main section of his zones, sketched a plan for grounding on this basis a more special representation of the starry firmament, his object being not simply to exhibit what had been already observed, but likewise to enable astronomers by the completeness of his tables at once to recognize every new celestial phenomenon. Although the star maps of the Berlin Academy of Sciences, sketched in accordance with Bessel's plan, may not have wholly completed the first proposed cycle, they have nevertheless contributed in a remarkable degree to the discovery of new planets, since they have been the principal if not the sole means to which, at the present time (1850), we owe the recognition of seven new planetary bodies."[23] Of the twenty-four maps designed to represent that portion of the heavens which extends 15° on either side of the equator, our Academy has already contributed sixteen. These contain, as far as possible, all stars down to the 9th magnitude and many of the 10th.

The present would seem a fitting place to refer to the average estimates which have been hazarded on the number of stars throughout the whole heavens, visible to us by the aid of our colossal space-penetrating telescopes. Struve assumes for Herschel's twenty-feet reflector, which was em-

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[2] Encke, *Gedächtnissrede auf Bessel*, s. 13.

ployed in making the celebrated *star-gauges* or *sweeps*, that a magnifying power of 180 would give 5800000 for the number of stars lying within the zones extending 30° on either side of the equator, and 20374000 for the whole heavens. Sir William Herschel conjectured that 18 millions of stars in the Milky Way, might be seen by his still more powerful forty-feet reflecting telescope.[24]

After a careful consideration of all the fixed stars, whether visible to the naked eye or merely telescopic, whose positions are determined, and which are recorded in catalogues, we turn to their distribution and grouping in the vault of heaven.

As we have already observed, these stellar bodies, from the inconsiderable and exceedingly slow (real and apparent) change of position exhibited by some of them—partly owing to precession and to the different influences of the progression of our solar system, and partly to their own proper motion—may be regarded as landmarks in the boundless regions of space, enabling the attentive observer to distinguish all bodies that move among them with a greater velocity or in an opposite direction—consequently all which are allied to telescopic comets and planets. The first and predominating interest excited by the contemplation of the heavens is directed to the fixed stars, owing to the multiplicity and overwhelming mass of these cosmical bodies; and it is by them that our highest feelings of admiration are called forth. The orbits of the planetary bodies appeal rather to inquiring reason, and, by presenting to it complicated problems, tend to promote the development of thought in relation to astronomy.

Amid the innumerable multitude of great and small stars which seem scattered, as it were by chance, throughout the vault of heaven, even the rudest nations separate single

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[24] Compare Struve, *Etudes d'Astr. stellaire*, 1847, pp. 66 and 72; *Cosmos*, vol. i. p. 140; and Mädler, *Astr.*, 4te Aufl. § 417.

(and almost invariably the same) groups, among which certain bright stars catch the observer's eye, either by their proximity to each other, their juxtaposition, or, in some cases, by a kind of isolation. This fact has been confirmed by recent and careful examinations of several of the languages of so-called savage tribes. Such groups excite a vague sense of the mutual relation of parts, and have thus led to their receiving names, which, although varying among different races, were generally derived from organic terrestrial objects. Amid the forms with which fancy animated the waste and silent vault of heaven, the earliest groups thus distinguished were the seven-starred Pleiades, the seven stars of the Great Bear, subsequently (on account of the repetition of the same form) the constellation of the Lesser Bear, the belt of Orion (Jacob's staff), Cassiopeia, the Swan, the Scorpion, the Southern Cross (owing to the striking difference in its direction before and after its culmination), the Southern Crown, the Feet of the Centaur (the Twins, as it were, of the Southern hemisphere), &c.

Wherever steppes, grassy plains or sandy wastes present a far-extended horizon, those constellations whose rising or setting corresponds with the busy seasons and requirements of pastoral and agricultural life, have become the subject of attentive consideration, and have gradually led to a symbolising connection of ideas. Men thus became familiarised with the aspect of the heavens before the development of measuring astronomy. They soon perceived that besides the daily movement from east to west, which is common to all celestial bodies, the sun has a far slower proper motion in an opposite direction. The stars which shine in the evening sky sink lower every day, until at length they are wholly lost amid the rays of the setting sun; while, on the other hand, those stars which were shining in the morning sky, before the rising of the sun, recede further and further from it. In the ever-changing aspect of the starry heavens, successive constellations are always coming to view. A slight degree of attention suffices to show that these are the same which had before vanished in the west; and that the stars which are opposite to the sun, setting at its rise, and rising at its setting, had about half-a-year earlier been seen in its vicinity. From the time of Hesiod to Eudoxus, and from the latter to Aratus and Hipparchus, Hellenic literature abounds in metaphoric allusions to the disappearance of the stars amid the sun's rays, and their appearance in the morning twilight,—their *heliacal* setting and rising. An attentive observation of these phenomena yielded the earliest elements of chronology, which were simply expressed in numbers, while mythology, in accordance with the more cheerful or gloomy tone of national character, continued simultaneously to rule the heavens with arbitrary despotism.

The primitive Greek sphere, (I here again, as in the history of the physical contemplation of the universe,[25] follow the investigations of my intellectual friend Letronne,) had become gradually filled with constellations, without being in any degree considered with relation to the ecliptic. Thus Homer and Hesiod designate by name individual stars and groups; the former mentions the constellation of the Bear ("otherwise known as the Celestial Wain, and which alone never sinks into the bath of Oceanos,") Bootes, and the Dog of Orion; the latter speaks of Sirius and Arcturus, and both refer to the Pleiades, the Hyades, and Orion.[26] Homer's twice repeated assertion that the constellation of the Bear *alone* never sinks into the ocean, merely allows us to infer that in his age, the Greek sphere did not yet comprise the constellations of Draco, Cepheus and Ursa Minor, which likewise do not set. The statement does not prove a want of acquaintance with the existence of the separate stars forming these three catasterisms, but simply an ignorance of their arrangement into constellations. A long and frequently misunderstood passage of Strabo (lib. i. p. 3, Casaub.) on Homer, *Il.* xviii. 485–489, specially proves a fact—important to the question,—that in the Greek sphere the stars were only *gradually* arranged in constellations. Homer has been unjustly accused of ignorance, says Strabo, as if he had known of only one instead of two Bears. It is probable that the lesser one had not yet been arranged in a separate group; and that the name did not reach the Hellenes, until after the Phœnicians had specially designated this constellation and made use of it for the purposes of navigation. All the scholia on Homer. Hyginus and Diogenes Laertius, ascribe its introduction to Thales. In the Pseudo-Eratosthenian work to which we have already referred, the lesser Bear is called Φοινίκη (or as it were the Phœnician guiding star). A century later (Ol. 71,) Cleostratus of Tenedos, enriched the sphere with the constellations of Sagittarius, Τοξότης, and Aries, Κριός.

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[25] *Cosmos*, p. 533.

[26] Ideler, *Unters. über die Sternnamen*, s. xi. 47, 139, 144, 243; Letronne, *Sur l'Origine du Zodiaque Grec*, 1840, p. 25.

The introduction of the Zodiac into the ancient Greek sphere coincides according to Letronne with this period of the domination of the Pisistratidæ. Eudemus of Rhodes, one of the most distinguished pupils of Aristotle, and author of a "History of Astronomy," ascribes the introduction of this Zodiacal belt ἡ τοῦ ζωδιακοῦ διάζωσις, also ζωίδιος κύκλος) to Œnopides of Chios, a contemporary of Anaxagoras.[27] The idea of the relation of the planets and fixed stars to the *sun's* course, the division of the ecliptic into twelve equal parts (Dodecatomeria) originated with the ancient Chaldeans, and very probably came to the Greeks, at the beginning of the fifth, or even in the sixth century before our era, direct from Chaldea, and not from the Valley of the Nile.[28] The Greeks merely separated from the constellations, named in their primitive sphere, those which were nearest to the ecliptic, and could be used as signs of the zodiac. If the Greeks had borrowed from another nation anything more than the idea and number of the divisions (Dodecatomeria) of a zodiac,—if they had borrowed the zodiac itself with its signs,—they would not at first have contented themselves with only eleven constellations. The Scorpion would not have been divided into two groups; nor would zodiacal constellations have been introduced, (some of which, like Taurus, Leo, Pisces, and Virgo, extend over a space of 35° to 48°, while others, as Cancer, Aries, and Capricornus, occupy only from

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[27] Letronne, *op. cit.*, p. 25; and Carteron, *Analyse des Recherches de M. Letronne sur les représentations zodiacales*, 1843, p. 119. "It is very doubtful whether Eudoxus (Ol. 103) ever made use of the word ζωδιακός. We first meet with it in Euclid, and in the Commentary of Hipparchus on Aratus (Ol. 160). The name ecliptic, εκλειπτικός, is also very recent." Compare Martin in the Commentary to *Theonis Smyrnæi Platonici Liber de Astronomia*, 1849, pp. 50, 60.

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[28] Letronne, *Orig. du Zod.*, p. 25; and *Analyse crit. des Représ. zod.*, 1846, p. 15. Ideler and Lepsius also consider it probable "that the knowledge of the Chaldean zodiac, as well in reference to its divisions as to the names of the latter, had reached the Greeks in the 7th century before our era, although the adoption of the separate signs of the zodiac in Greek astronomical literature was gradual and of a subsequent date." (Lepsius, *Chronologie der Ægypter*, 1849, s. 65 and 124.) Ideler is inclined to believe that the Orientals had names but not constellations for the Dodecatomeria, and Lepsius regards it as a natural assumption "that the Greeks at the period when their sphere was for the most part unfilled should have added to their own the Chaldean constellations, from which the twelve divisions were named." But are we not led on this supposition to inquire why the Greeks had at first only eleven signs instead of introducing all the twelve belonging to the Chaldean dodecatomeria? If they introduced the twelve signs they are hardly likely to have removed one in order to replace it at a subsequent period.

19° to 23°), which are inconveniently grouped to the north and south of the ecliptic, either at great distances from each other, or, like Taurus and Aries, Aquarius and Capricornus, so closely crowded together as almost to encroach on each other. These circumstances prove that catasterisms previously formed were converted into signs of the zodiac.

The sign of Libra, according to Letronne's conjecture, was introduced at the time of, and perhaps by Hipparchus. It is never mentioned by Eudoxus, Archimedes, Autolycus, or even by Hipparchus in the few fragments of his writings which have been transmitted to us (excepting indeed in one passage, probably falsified by a copyist.)[20] The earliest notice of this new constellation occurs in

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[20] On the passage referred to in the text, and interpolated by a copyist of Hipparchus, see Letronne, *Orig. du Zod.*, 1840, p. 20. As early as 1812, when I was much disposed to believe that the Greeks had been long acquainted with the sign of Libra, I directed attention in an elaborate memoir (on all the passages in Greek and Roman writers of antiquity, in which the Balance occurs as a sign of the zodiac) to that passage in Hipparchus (*Comment. in Aratum*, lib. iii. cap. 2) which refers to the θηριὸν held by the Centaur (in his fore-foot) as well as to the remarkable passage of Ptolemy, lib. ix. cap. 7 (Halma, t. ii. p. 170). In the latter the Southern Balance is named with the affix κατὰ Χαλδαίους, and is opposed to the pincers of the Scorpion in an observation, which was undoubtedly not made at Babylon, but by some of the astrological Chaldeans, dispersed throughout Syria and Alexandria. (*Vues des Cordillères et Monumens des peuples indigènes de l'Amérique*, t. ii. p. 380.) Buttman maintained, what is very improbable, that the χηλαὶ originally signified the two scales of the Balance, and were subsequently by some misconception converted into the pincers of a Scorpion. (Compare Ideler, *Untersuchungen uber die astronomischen Beobachtungen der Alten.*, s. 374, and *Ueber die Sternnamen*, s. 174–177, with Carteron, *Recherches de M. Letronne*, p. 113.) It is a remarkable circumstance connected with the analogy between

Geminus and Varro, scarcely half a century before our era; and as the Romans, from the time of Augustus to Antoninus, became more strongly imbued with a predilection for astrological inquiry, those constellations which "lay in the celestial path of the sun" acquired an exaggerated and fanciful importance. The Egyptian zodiacal constellations found at Dendera, Esneh, the Propylon of Panopolis, and on some mummy-cases, belong to the first half of this period of the Roman dominion, as was maintained by Visconti and Testa, at a time when the necessary materials for the decision of the question had not been collected, and the wildest hypothesis still prevailed regarding the signification of these symbolical zodiacal signs, and their dependence on the precession of the equinoxes. The great antiquity which, from passages in Manu's Book of Laws, Valmiki's Ramayana and Amarasinha's Dictionary, Augustus William von Schlegel attributed to the zodiacal circles found in India, has been rendered very doubtful by Adolph Holtzmann's ingenious investigations.[30]

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many of the names of the twenty-seven "houses of the moon," and the Dodecatomeria of the zodiac, that we also meet with the sign of the Balance among the Indian Nakschatras (Moon-houses), which are undoubtedly of very great antiquity. (*Vues des Cordillères*, t. ii. pp. 6–12.)

[30] Compare A. W. von Schlegel *Ueber Sternbilder des Thierkreises im alten Indien*, in the *Zeitschrift für die Kunde des Morgenlandes*, bd. i. Heft 3. 1837, and his *Commentatio de Zodiaci antiquitate et origine*, 1839, with Adolph Holtzman, *Ueber den griechischen Ursprung des indischen Thierkreises*, 1841, s. 9, 16, 23. "The passages quoted from Amorakoscha, and Ramayana," says the latter writer, "admit of undoubted interpretation, and speak of the zodiac in the clearest terms; but if these works were composed before the knowledge of the Greek signs of the zodiac could have reached India, these passages ought to be carefully examined for the purpose of ascertaining whether they may not be comparatively modern interpolations."

The artificial grouping of the stars into constellations which arose incidentally during the lapse of ages—the frequently inconvenient extent and indefinite outline—the complicated designations of individual stars in the different constellations—the various alphabets which have been required to distinguish them, as in Argo—together with the tasteless blending of mythical personages with the sober prose of philosophical instruments, chemical furnaces, and pendulum clocks, in the southern hemisphere—have led to many propositions for mapping the heavens in new divisions, without the aid of imaginary figures. This undertaking appears least hazardous in respect to the southern hemisphere, where Scorpio, Sagittarius, Centaurus, Argo, and Eridanus alone possess any poetic interest.[31]

The heavens of the fixed stars (*orbis inerrans* of Apuleius) and the inappropriate expression of *fixed stars*, (*astra fixa* of Manilius) remind us, as we have already observed in the introduction to the Astrognosy,[32] of the connexion, or rather confusion of the ideas of insertion, and of absolute immobility or fixity. When Aristotle calls the non-wandering celestial bodies (ἀπλανῆ ἄστρα) *rivetted* (ἐνδεδεμένα), when Ptolemy designates them as engrafted (προσπεφυκότες), these terms refer specially to the idea entertained by Anaximenes of the crystalline sphere of heaven. The apparent motion of all the fixed stars from east to west, while their relative distances remained unchanged, had given rise to this hypothesis. "The fixed stars (ἀπλανῆ ἄστρα) belong to the higher and more distant regions, in which they are rivetted, like nails, to the crystalline heavens; the planets (ἄστρα πλανώμενα or πλανητά), which move in an opposite direction, belong to a lower and nearer region."[33] As we find in Manilius, in the earliest ages of the Cæsars, that the term *stella fixa* was substituted for *infixa*, or *affixa*, it may be assumed that the schools of Rome attached thereto at first only the original signification of *rivetted*, but as the word *fixus* also embraced the idea of immobility, and might even be regarded as synonymous with *immotus* and *immobilis*, we may readily conceive that the national opinion, or rather usage of speech, should gradually have associated with *stella fixa* the idea of immobility, without reference to the fixed sphere to which it was attached. In this sense Seneca might term the world of the fixed stars *fixum et immobilem populum.*

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[31] Compare Buttman, in *Berlin astron. Jahrbuch für* 1822, s. 93, Olbers on the more recent constellations in Schumacher's *Jahrbuch für* 1840, s. 283–251, and Sir John Herschel, *Revision and Rearrangement of the Constellations, with special reference to those of the Southern Hemisphere*, in the *Memoirs of the Astr. Soc.*, vol. xii. pp. 201–224, (with a very exact distribution of the southern stars from the 1st to the 4th magnitude). On the occasion of Lalande's formal discussion with Bode on the introduction of his domestic cat and of a reaper (*Messier!*) Olbers complains that in order "to find space in the firmament for King Frederick's glory, Andromeda must lay her right arm in a different place from that which it had occupied for 3000 years!"

[32] Vide supra, pp. 30–31, and note.

Although, according to Stobæus, and the collector of the "Views of the Philosophers," the designation "crystal vault of heaven" dates as far back as the early period of Anaximenes, the first clearly defined signification of the idea on which the term is based, occurs in Empedocles. This philosopher regarded the heaven of the fixed stars as a solid mass, formed from the ether which had been rendered crystalline and rigid by the action of fire.[34]

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[33] According to Democritus and his disciple Metrodorus, Stob. *Eclog. phys.*, p. 582.

[34] Plut. *de plac. phil.* ii. 11; Diog. Laert., viii. 77; Achilles Tat. ad Arat. cap. 5, Εμπ·, κρυσταλλώη τοῦτον (τὸν οὐρανὸν) εἰναί φησιν, εκ τοῦ παγετώδους συλλεγέντα; in like manner we only meet with the expression *crystal-like* in Diog. Laert., viii. 77, and Galenus, *Hist. phil.*, 12, (Sturz, *Empedocles Agrigent.* t. i. p. 321). Lactantius *de opificio Dei*, c. 17. "An, si mihi quispiam dixerit *æneum* esse cœlum, aut *vitreum*, aut,

According to his theory the moon is a body conglomerated (like hail) by the action of fire, and receives its light

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ut Empedocles ait, aerem *glaciatum*, statimne assentiat quia cælum ex qua materia sit, ignorem." "If any one were to tell me that the heavens are made of brass, or of glass, or, as Empedocles asserts, of frozen air, I should incontinently assent thereto, for I am ignorant of what substance the heavens are composed." We have no early Hellenic testimony of the use of this expression of a glass-like or vitreous heaven (*cælum vitreum*), for only one celestial body, the sun, is called by Philolaus, a glass-like body, which throws upon us the rays it has received from the central fire. (The view of Empedocles, referred to in the text, of the reflection of the sun's light from the body of the moon, (supposed to be consolidated in the same manner as hail-stones,) is frequently noticed by Plutarch, *apud Euseb. Præp. Evangel.* 1, pag. 24. D, and *de facie in orbe Lunæ*, cap. 5). Where *Uranos* is described as χαλκεὸς and σιδήρεος by Homer and Pindar, the expression refers only to the idea of steadfast, permanent, and imperishable, as in speaking of brazen hearts and brazen voices. Völcker *über Homerische Geographie*, 1830, s. 5. The earliest mention before Pliny, of the word κρύσταλλος when applied to ice-like, transparent rock-crystal occurs in Dionysius Periegetes, 781, Aelian, xv. 8, and Strabo, xv. p. 717, Casaub. The opinion, that the idea of the crystalline heavens being a glacial vault (*aer glaciatus* of Lactantius) arose amongst the ancients, from their knowledge of the decrease of temperature, with the increase of height in the strata of the atmosphere, as ascertained from ascending great heights and from the aspect of snow-covered mountains, is refuted by the circumstance that they regarded the fiery ether as lying beyond the confines of the actual atmosphere, and the stars as *warm* bodies. (Aristot., *Meteor.* 1, 3, *de Cælo*, 11, 7, p. 289). In speaking of the music of the spheres (Aristot. *de Cælo*, 11, p. 290), which according to the views of the Pythagoreans is not perceived by men, because it is continuous, whereas tones can only be heard when they are interrupted by silence, Aristotle singularly enough maintains that the movement of the spheres generates heat in the air below them, while they are themselves not heated.

from the sun. The original idea of transparency, congelation, and solidity, would not, according to the physics of the

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Their vibrations produce heat, but no sound. "The motion of the sphere of the fixed stars is the most rapid, (Aristot. *de Cœlo*, ii. 10, p. 291); as this sphere and the bodies attached to it are impelled in a circle, the subjacent space is heated by this movement, and hence heat is diffused to the surface of the earth." (*Meteorol.* 1, 3, p. 340.) It has always struck me as a circumstance worthy of remark, that the Stagirite should constantly avoid the word *crystal heaven;* for the expression, "*rivetted stars*" (*ἐνδεδεμένα ἄστρα*), which he uses, indicates a general idea of solid spheres, without, however, specifying the nature of the substance. We do not meet with any allusion to the subject in Cicero, but we find in his Commentator Macrobius, (*Cic. Somnium Scipionis*, 1, c. 20, p. 99, ed. Bip.) traces of freer ideas on the diminution of temperature, with the increase of height. According to him, eternal cold prevails in the outermost zones of heaven. "Ita enim non solum terram sed ipsum quoque cœlum, quod vere mundus vocatur, temperari a sole certissimum est, ut extremitates ejus, quæ via solis longissime recesserunt, omni careant beneficio caloris, et una frigoris perpetuitate torpescant." "For as it is most certain that, not only the earth, but the heavens themselves, which are truly called the universe, are rendered more temperate by the sun, so also their confines, which are most distant from the sun, are deprived of the benefits of heat, and languish in a state of perpetual cold." These confines of heaven (*extremitates cœli*), in which the Bishop of Hippo (Augustinus, ed. Antv. 1700, 1, p. 102, and iii. p. 99) placed a region of icy-cold water near Saturn the highest, and therefore the coldest, of all the planets, are within the actual atmosphere, for beyond the outer limits of this space lies, according to a somewhat earlier expression of Macrobius, (1, c. 19, p. 93,) the fiery ether which enigmatically enough, does not prevent this eternal cold: "Stellæ supra cœlum locatæ, in ipso purissimo æthere sunt, in quo omne quidquid est, lux naturalis et sua est, quæ tota cum igne suo ita sphæræ solis incumbit, ut cœli zonæ, quæ procul a sole sunt, perpetuo frigore oppressæ sint." "The stars above the heavens are situated in the pure ether, in which all ancients,[35] and their ideas of the solidification of fluids, have referred directly to cold and ice; but the affinity between *κρύσταλλος*, *κρύος*, and *κρυσταίνω*, as well as this comparison with the most transparent of all bodies gave rise to the more definite assertion that the vault of heaven consisted of ice or of glass. Thus we read in Lactantius: "Cœlum aerem glaciatum esse," and "vitreum cœlum." Empedocles undoubtedly did not refer to the glass of the Phœnicians, but to air, which was supposed to be condensed into a transparent solid body by the action of the fiery ether. In this comparison with ice, (*κρύσταλλος*) the idea of transparency predominated; no reference being here made to the origin of ice through cold, but simply to its conditions of transparent condensation. While poets used the term crystal, prose writers (as found in the note on the passage cited from Achilles Tatius, the commentator of Aratus) limited themselves to the expression *crystalline* or *crystal-like*, *κρυσταλλοέιδής*. In like manner *παγος* (from *πήγνυσθαι*, to become solid), signifies a piece of ice —its condensation being the sole point referred to.

The idea of a crystalline vault of heaven was handed down to the middle ages by the Fathers of the Church, who believed the firmament to consist of from 7 to 10 glassy strata, incasing one another like the different coatings of an onion. This supposition still keeps its ground in some of the monasteries of

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things, whatever they may be, have a natural and proper light of their own," (the region of self-luminous stars) "which so impends over the sphere of the sun with all its fire, that those zones of heaven which are far from the sun are oppressed by perpetual cold." My reason for entering so circumstantially into the physical and meteorological ideas of the Greeks and Romans, is simply because these subjects, except in the works of Ukert, Henri Martin, and the admirable fragment of the *Meteorologia Veterum* of Julius Ideler, have hitherto been very imperfectly, and for the most part superficially, considered.

[35] The ideas that fire has the power of making rigid, (Aristot.

Southern Europe, where I was greatly surprised to hear a venerable prelate express an opinion in reference to the fall of aerolites at Aigle, which at that time formed a subject of considerable interest, that the bodies we called meteoric stones with vitrified crusts were not portions of the fallen stone itself, but simply fragments of the crystal vault shattered by it in its fall. Kepler, from his considerations of comets which intersect the orbits of all the planets,[36] boasted, nearly two hundred and fifty years ago, that he had destroyed the 77 concentric spheres of the celebrated Girolamo Fracastoro, as well as all the more ancient retrograde epicycles. The ideas entertained by such great thinkers as Eudoxus, Menæchmus, Aristotle, and Apollonius Pergæus, respecting the possible mechanism and motion of these solid, mutually intersecting spheres by which the planets were moved; and the question whether they regarded these systems of rings as mere ideal modes of representation, or intellectual fancies, by means of which difficult problems of the planetary orbits might be solved or determined approximately; are subjects of which I have already treated

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*Probl.*, xiv. 11,) and that the formation of ice itself may be promoted by heat, are deeply-rooted in the physics of the ancients, and based on a fanciful theory of contraries (*Antiperistasis*)—on obscure conceptions of polarity (of exciting opposite qualities or conditions). (*Cosmos*, p. 14, and note.) The quantity of hail produced was considered to be proportional to the degree of heat of the atmospheric strata. (Aristot. *Meteor.*, i. 12.) In the winter fishery on the shores of the Euxine, warm water was used to increase the ice formed in the neighbourhood of an upright tube. (Alex. Aphrodis., fol. 86, and Plut. *de primo frigido*, c. 12.)

[36] Kepler expressly says in his *Stella Martis*, fol. 9: "Solidos orbes rejeci." "I have rejected the idea of solid orbs;" and in the *Stella Nova*, 1606, cap. 2, p. 8: "Planetæ in puro æthere, perinde atque aves in aëre cursus suos conficiunt." "The planets perform their course in the pure ether as birds pass through the air." Compare, also, p. 122. He in-

in another place,[37] and which are not devoid of interest in our endeavours to distinguish the different periods of development which have characterised the history of astronomy.

Before we pass from the very ancient, but artificial zodiacal grouping of the fixed stars, as regards their supposed insertion into solid spheres, to their natural and actual arrangement, and to the known laws of their relative distribution, it will be necessary more fully to consider some of the sensuous phenomena of the individual cosmical bodies—their extending rays, their apparent, spurious disc, and their differences of colour. In the note referring to the invisibility of Jupiter's satellites,[38] I have already spoken of the influence of the so-called tails of the stars, which vary in number, position, and length in different individuals. Indistinctness of vision (*la vue indistincte*) arises from numerous organic causes, depending on aberration of the sphericity of the eye, diffraction at the margins of the pupil, or at the eye-lashes, and on the more or less widely diffused irritability of the retina from the excited point.[39] I see very regularly eight rays at angles of 45°

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clined, however, at an earlier period, to the idea of a solid icy vault of heaven congealed from the absence of solar heat: "Orbis ex aqua factus gelu concreta propter solis absentiam." (Kepler, *Epit. Astr. Copern.*, i. 2, p. 51.) Two thousand years before Kepler, Empedocles maintained that the fixed stars were rivetted to the crystal heavens, but that the planets were free and unrestrained" (τοὺς δε πλανήτας ανεῖσθαι). (Plut. *plac. phil.*, ii. 13; Emped. 1, p. 335 Sturz; Euseb. *Præp. evang.*, xv. 30, col. 1688, p. 839.) It is difficult to conceive how, according to Plato in the Timæus (*Tim.*, p. 40, B., see Bohn's edition of Plato, vol. ii. p. 344, but not according to Aristotle,) the fixed stars, rivetted as they are to solid spheres, could rotate independently.

[37] *Cosmos*, vol. ii. pp. 696–7.

[38] Vide supra, p. 64, and note.

[39] "Les principales causes de la vue indistincte sont: aberration de sphéricité de l'œil, diffraction sur les bords de la pupille, communication d'irritabilité à des points voisins sur la

in stars from the 1st to the 3rd magnitude. As, according to Hassenfratz, these radiations are caustics intersecting one

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rétine. La vue confuse est celle où le foyer ne tombe pas exactement sur la rétine, mais tombe au-devant ou derrière la rétine. Les queues des étoiles sont l'effet de la vision indistincte, autant qu'elle dépend de la constitution du cristallin. D'après un très ancien mémoire de Hassenfratz (1809) ‘ les queues au nombre de 4 ou 8 qu'offrent les étoiles ou une bougie vue à 25 mètres de distance, sont les caustiques du cristallin formées par l'intersection des rayons réfractés.’ Ces caustiques se meuvent à mesure que nous inclinons la tête.—La propriété de la lunette de terminer l'image fait qu'elle concentre dans un petit espace la lumière qui sans cela en aurait occupé un plus grand. Cela est vrai pour les étoiles fixes et pour les disques des planètes. La lumière des étoiles qui n'ont pas de disque réels, conserve la même intensité, quel que soit le grossissement. Le fond de l'air duquel se détache l'étoile dans la lunette, devient plus noir par le grossissement qui dilate les molécules de l'air qu'embrasse le champ de la lunette. Les planètes à vrais disques deviennent elles-mêmes plus pâles par cet effet de dilatation.—Quand la peinture focale est nette, quand les rayons partis *d'un point* de l'objet se sont concentrés en *un seul point* dans l'image, l'oculaire donne des résultats satisfaisants. Si au contraire les rayons émanés d'un point ne se réunissent pas au foyer en un seul point, s'ils y forment *un petit cercle*, les images de deux points contigus de l'objet empiètent nécessairement l'une sur l'autre ; leurs rayons se confondent. Cette confusion la lentille oculaire ne saurait la faire disparaître. L'office qu'elle remplit exclusivement, c'est de grossir ; elle grossit tout ce qui est dans l'image, les défauts comme le reste. Les étoiles n'ayant pas de diamètres angulaires sensibles, ceux qu'elles conservent toujours, tiennent pour la plus grande partie au manque de perfection des instrumens (à la courbure moins régulière donnée aux deux faces de la lentille objective) et à quelques défauts et aberrations de notre œil. Plus une étoile semble petite, tout étant égal quant au diamètre de l'objectif, au grossissement employé et à l'éclat de l'étoile observée, et plus la lunette a de perfection. Or le meilleur moyen de juger si les étoiles sont très petites, si des points sont représentés au foyer par des simples points, c'est another on the crystalline lens, they necessarily move according to the direction in which the head is in-

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évidemment de viser à des étoiles excessivement rapprochées entr'elles et de voir si dans les étoiles doubles connues les images se confondent, si elles empiètent l'une sur l'autre, ou bien si on les aperçoit bien nettement séparées."

"The principal causes of indistinct vision are: aberration of the sphericity of the eye, diffraction at the margins of the pupil, and irritation transmitted to contiguous points of the retina. Indistinct vision exists where the focus does not fall exactly on the retina, but either somewhat before or behind it. The tails of the stars are the result of indistinctness of vision, as far as it depends on the constitution of the crystalline lens. According to a very old paper of Hassenfratz (1809) 'the 4 or 8 tails which surround the stars or a candle seen at a distance of 25 metres [82 feet], are the caustics formed on the crystalline lens by the intersection of refracted rays.'—These caustics follow the movements of the head.—The property of the telescope in giving a definite outline to images, causes it to concentrate in a small space, the light which would otherwise be more widely diffused. This obtains for the fixed stars and for the discs of planets. The light of stars having no actual discs, maintains the same intensity, whatever may be the magnifying power of the instrument. The aerial field from which the star is projected in the telescope is rendered more black by the magnifying property of the instrument, by which the molecules of air included in the field of view are expanded. Planets having actual discs become fainter from this effect of expansion. When the focal image is clearly defined, and when the rays emanating from one point of the object are concentrated into one point in the image, the ocular focus affords satisfactory results. But if, on the contrary, the rays emanating from one point do not reunite in the focus into one point, but form a *small circle*, the images of two contiguous points of the object will necessarily impinge upon each other; and their rays will be confused. This confusion cannot be removed by the ocular; since the only part it performs is that of magnifying. It magnifies everything comprised in the image, including its defects. As the stars have no sensible angular diameters, those which they present are principally clined.[40] Some of my astronomical friends see three, or at most four rays above, and none below the star. It has always appeared extraordinary to me, that the ancient Egyptians should invariably have given only five rays to the stars (at distances, therefore, of 72°); so that a star in hieroglyphics signifies, according to Horapollo, the number five.[41]

The rays of the stars disappear when the image of the radiating star is seen through a very small aperture made with a needle in a card, and I have myself frequently observed both Canopus and Sirius in this manner. The same thing occurs in telescopic vision through powerful instruments, when the stars appear either as intensely luminous points, or as exceedingly small discs. Although the fainter scintillation of the fixed stars in the tropics conveys a certain impression of repose, a total absence of stellar radiation would, in my opinion, impart a desolate aspect to the firmament, as seen by the naked eye. Illusion of the senses, optical illusion, and indistinct vision, probably tend to augment the splendour of the luminous canopy of heaven. Arago long since proposed

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owing to the imperfect construction of the instrument (to the different curvatures of the two sides of the object-glass), and to certain defects and aberrations pertaining to the eye itself. The smaller the star appears, the more perfect is the instrument, providing all relations are equal as to the diameter of the object-glass, the magnifying power employed, and the brightness of the star. Now the best means of judging whether the stars are very small, and whether the points are represented in the focus by simple points, is undoubtedly that of directing the instrument to stars situated very near each other, and of observing whether the images of known double stars are confused, and impinging on each other, or whether they can be seen separate and distinct." (Arago, *M.S. of* 1834 *and* 1847.)

[40] Hassenfratz, *Sur les rayons divergens des Etoiles* in Delamétherie, *Journal de Physique*, tom. lxix. 1809, p. 324.

[41] *Horapollinis Niloi Hieroglyphica*, ed. Con. Leemans,

the question, why fixed stars of the first magnitude, notwithstanding their great intensity of light, cannot be seen when rising above the horizon in the same manner as under similar circumstances we see the outer margin of the moon's disc.[42]

Even the most perfect optical instruments, and those having the highest magnifying powers, give to the fixed stars spurious discs (diamètres factices); "the greater aperture," according to Sir John Herschel, "even with the same magnifying power giving the smaller disc."[43] Occultations of the stars by the moon's disc show that the period occupied in the immersion and emersion is so transient that it cannot be estimated at a fraction of a second of time. The frequent occurrence of the so-called adhesion of the immersed star to the moon's disc, is a phenomenon depending on inflection of light in no way connected with the question of the spurious diameter of the star. We have already seen that Sir William Herschel, with a magnifying power of 6500, found the diameter of Vega 0″·36. The image of Arcturus was so diminished in a dense mist, that the disc was below 0″·2. It is worthy of notice that, in consequence of the illusion occasioned by stellar radiation, Kepler and Tycho, before the invention

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1835, cap. 13, p. 20. The learned editor notices, however, in refutation of Jomard's assertion (*Descr. de l'Egypte*, tom. vii. p. 423), that a star, as the numerical hieroglyphic for 5, has not yet been discovered on any monument or papyrus-roll. (Horap., p. 194.)

[42] I found an opinion prevalent among the sailors of the Spanish ships of the Pacific, that the age of the moon might be determined before the first quarter, by looking at it through a piece of silk and counting the multiplied images. Here we have a phenomenon of *diffraction* observed through fine slits.

[43] *Outlines*, § 816. Arago has caused the spurious diameter of Aldebaran to increase from 4″ to 15″ in the instrument by diminishing the object-glass.

of the telescope, respectively ascribed to Sirius[44] a diameter of 4′ and of 2′ 20″.

The alternating light and dark rings which surround the small spurious discs of the stars when magnified two or three hundred times, and which appear iridescent when seen through diaphragms of different form, are likewise the result of interference and diffraction, as we learn from the observations of Arago and Airy. The smallest objects which can be distinctly seen in the telescope as luminous points, may be employed as a test of the perfection in construction and illuminating power of optical instruments, whether refractors or reflectors. Amongst these we may reckon multiple stars, such as ε Lyræ, and the 5th and 6th star discovered by Struve, in 1826, and by Sir John Herschel in 1832, in the trapezium of the great nebula of Orion,[45] forming the quadruple star θ of that constellation.

A difference of colour in the proper light of the fixed stars, as well as in the reflected light of the planets, was recognized at a very early period; but our knowledge of this remarkable phenomenon has been greatly extended by the aid of telescopic vision, more especially since attention has been so especially directed to the double stars. We do not here allude to the change of colour which, as already observed, accompanies scintillation even in the whitest stars, and still less to the transient and generally red colour exhibited by stellar light near the horizon, (a phenomenon owing to the character of the atmospheric medium through which we see it,) but to the white or coloured stellar light radiated from each cosmical body, in consequence of its peculiar luminous process, and the different constitution of its surface. The Greek astronomers were acquainted with red stars only, while modern science has discovered, by the aid of the telescope, in the radiant fields of the starry heaven, as in the blossoms of the phanerogamia, and in the metallic oxides, almost all the gradations of the prismatic spectrum between the extremes of refrangibility of the red and the violet ray. Ptolemy enumerates in his catalogue of the fixed stars six (ὑπόκιῤῥοι) *fiery red* stars, viz:[46] Arcturus Aldebaran. Pollux, Antares, *α* Orionis (in the right shoulder), and Sirius. Cleomedes even compares Antares in Scorpio with the fiery red Mars,[47] which is called both *πυῤῥὸς* and *πυροειδὴς.*

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[44] Delambre, *Hist. de l'Astr. moderne*, tom. i. p. 193; Arago, *Annuaire*, 1842, p. 366.

[45] "Two excessively minute, and very close companions, to perceive *both* of which, is one of the severest tests which can be applied to a telescope." (*Outlines*, § 837. Compare also Sir John Herschel, *Observations at the Cape*, p. 29; and Arago, in the *Annuaire pour* 1834, pp. 302–305.) Among the different planetary cosmical bodies by which the illuminating power of a strongly magnifying optical instrument may be tested, we may mention the 1st and 4th satellites of Uranus, rediscovered by Lassell and Otto Struve in 1847, the two innermost and the 7th satellite of Saturn (Mimas, Enceladus, and Bond's Hyperion), and Neptune's satellite discovered by Lassell. The power of penetrating into celestial space occasioned Bacon, in an eloquent passage in praise of Galileo, to whom he erroneously ascribes the invention of telescopes, to compare these instruments to ships which carry men upon an unknown ocean:—"Ut propriora exercere possint cum cœlestibus commercia." (*Works of Francis Bacon*, 1740, vol. i. *Novum Organum*, p. 361.)

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[46] The expression ὑπόκιῤῥος, which Ptolemy employs indiscriminately to designate the six stars named in his catalogue, implies a slightly marked transition from *fiery-yellow* to *fiery-red;* it therefore refers, strictly speaking, to *a fiery-reddish* colour. He seems to attach the general predicate ξανθός, *fiery-yellow*, to all the other fixed stars. (*Almag*., viii. 3 ed. Halma, tom. ii. p. 94.) Κιῤῥός is, according to Galen, (*Meth. med*. 12,) a pale fiery-red inclining to yellow. Gellius compares the word with *melinus*, which, according to Servius, has the same meaning as "gilvus" and "fulvus." As Sirius is said by Seneca (*Nat. Quæst*., i. 1) to be *redder than Mars*, and belongs to the stars called in the Almagest ὑπόκιῤῥοι, there can be no doubt that the word implies the predominance, or, at all events, a certain proportion of red rays. The assertion that the affix ποικίλος, which Aratus, v. 327, attaches to

Of the six above named stars, five still retain a red or reddish light. Pollux is still indicated as a reddish, but Castor as a greenish star.[48] Sirius therefore affords the only example of an historically proved change of colour, for it has at present a perfectly white light. A great physical revolution[49] must therefore have occurred at the surface or in the photosphere of this fixed star, (or *remote sun*, as Aristarchus of Samos called the fixed stars) before the process could have been disturbed by means of which the less refrangible red rays had obtained the preponderance, through the abstraction or absorption of other complementary

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Sirius, has been *translated* by Cicero as "rutilus," is erroneous. Cicero says, indeed, v. 348:—

"Namque pedes subter rutilo cum lumine claret,
Fervidus ille Canis stellarum luce refulgens;"

but "rutilo cum lumine" is not a *translation* of *ποικίλος*, but the mere addition of a free translation. (From letters addressed to me by Professor Franz.) "If," as Arago observes (*Annuaire*. 1842, p. 351), "the Roman orator, in using the term *rutilus*, purposely departs from the strict rendering of the Greek of Aratus, we must suppose that he recognized the reddish character of the light of Sirius."

[47] Cleom., *Cycl. Theor.*, i. ii. p. 59.

[48] Mädler. *Astr.* 1849, s. 391.

[49] Sir John Herschel, in the *Edinb. Review*, vol. 87, 1848, p. 189, and in Schum. *Astr. Nachr.*, 1839, no. 372:— "It seems much more likely that in Sirius a red colour should be the effect of a medium interfered, than that in the short space of 2000 years so vast a body should have actually undergone such a material change in its physical constitution. It may be supposed owing to the existence of some sort of *cosmical cloudiness*, subject to internal movements, depending on causes of which we are ignorant." (Compare Arago in the *Annuaire pour* 1842, pp. 350–353.)

rays, either in the photosphere of the star itself, or in the moving cosmical clouds by which it is surrounded. It is to be wished that the epoch of the disappearance of the red colour of Sirius had been recorded by a definite reference to the time, as this subject has excited a vivid interest in the minds of astronomers since the great advance made in modern optics. At the time of Tycho Brahe the light of Sirius was undoubtedly already white, for when the new star which appeared in Cassiopeia, in 1572, was observed in the month of March, 1573, to change from its previous dazzling white colour to a reddish hue, and again became white in January, 1574, the red appearance of the star was compared to the colour of Mars and Aldebaran, but not to that of Sirius. M. Sédillot, or other philologists conversant with Arabic and Persian astronomy, may perhaps some day succeed in discovering evidence of the earlier colour of Sirius, in the periods intervening from El-Batani (Albategnius) and El-Fergani (Alfraganus) to Abdurrahman Sufi and Ebn-Junis (that is, from 880 to 1007), and from Ebn-Junis to Nassir-Eddin and Ulugh-Beg (from 1007 to 1437).

El-Fergani (properly Mohammed Ebn-Kethir El-Fergani), who conducted astronomical observations in the middle of the tenth century at Rakka (Aracte) on the Euphrates, indicates as red stars (*stellæ ruffæ* of the old Latin translation of 1590) Aldebaran, and, singularly enough,[50] Capella, which is now yellow and has scarcely a tinge of red, but he does not mention Sirius. If at this period Sirius had been no longer red, it would certainly be a striking fact that El-Fergani, who invariably follows Ptolemy, should not here indicate the change of colour in so celebrated a star. Negative proofs are however not often conclusive, and indeed El-Fergani makes no reference in the same passage to the colour of Betelgeux (α Orionis), which is now red, as it was in the age of Ptolemy.

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[50] In *Muhamedis Alfragani chronologica et astronomica Elementa*, ed. Jacobus Christmannus, 1590, cap. 22, p. 97, we read:—"Stella ruffa in Tauro Aldebaran; stella ruffa in *Geminis* quæ appellatur *Hajok*, hoc est Capra." *Alhajoc*, *Aijuk* are, however, the ordinary names for Capella Aurigæ,

It has long been acknowledged that of all the brightest luminous fixed stars of heaven, Sirius takes the first and most important place, no less in a chronological point of view, than through its historical association with the earliest development of human civilization in the valley of the Nile. The era of Sothis—the heliacal rising of Sothis (Sirius)—on which Biot has written an admirable treatise, indicates, according to the most recent investigations of Lepsius,[51] the complete arrangements of the Egyptian calendar into those ancient epochs, including nearly 3300 years before our era, "when not only the summer solstice, and consequently the beginning of the rise of the Nile, but also the heliacal rising of Sothis, fell on the day of the first water-month (or the first Pachon)." I will collect in a note the most recent, and hitherto unpublished, etymological researches on Sothis or Sirius from the Coptic, Zend, Sanscrit, and Greek, which may perhaps be acceptable to those who, from love for the history of astronomy, seek

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in the Arabic and Latin Almagest. Argelander justly observes, in reference to this subject, that Ptolemy in the astrological work (Τετράβιβλος σύνταξις), the genuine character of which is testified by the style as well as by ancient evidence, has associated planets with stars according to similarity of colour, and has thus connected Martis stella, *Quæ urit sicut congruit igneo ipsius colori*, with Aurigæ stella, or Capella. (Compare Ptol., *Quadripart. Construct.*, libri iv. Basil, 1551, p. 383.) Riccioli (*Almagestum novum*, ed. 1650, tom. i. pars i. lib. 6, cap. 2, p. 394) also reckons Capella together with Antares, Aldebaran. and Arcturus among red stars.

[51] See *Chronologie der Ægypter*, by Richard Lepsius, bd. i. 1849, s. 190–195, 213. The complete arrangement of the Egyptian calendar is referred to the earlier part of the year 3285 before our era, *i. e.* about a century and a half after the

in languages and their affinities, monuments of the earlier conditions of knowledge.[52]

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building of the great pyramid of Cheops-Chufu, and 940 years before the period generally assigned to the Deluge. (Compare *Cosmos*, vol. ii. p. 475 and note.) In the calculations based on the circumstance of Colonel Vyse having found that the inclination of the narrow subterranean passage leading into the interior of the pyramid, very nearly corresponded to the angle 26° 15′, which, in the time of Cheops (Chufu), was attained by the star α Draconis, which indicated the pole, at its inferior culmination at Gizeh, the date of the building of the pyramid is not assumed at 3430 B.C, as given in *Cosmos* according to Letronne, but at 3970 B.C. (*Outlines of Astr.*, § 319.) This difference of 540 years tends to strengthen the assumption, that α Drac. was regarded as the pole-star, as in 3970 it was still at a distance of 3° 44′ from the pole.

[52] I have extracted the following observations from letters addressed to me by Professor Lepsius (February, 1850). "The Egyptian name of Sirius is *Sothis*, designated as a female star; hence, ἡ Σῶθις is identified in Greek with the goddess *Sote* (more frequently *Sit* in hieroglyphics,) and in the temple of the great Ramses at Thebes with Isis-Sothis (Lepsius, *Chron. der Ægypter*, bd. i. s. 119, 136). The signification of the root is found in Coptic, and is allied with a numerous family of words, the members of which, although they apparently differ very widely from each other, admit of being arranged somewhat in the following order. By the threefold transference of the verbal signification, we obtain from the original meaning, to throw out—*projicere* (*sagittam*, *telum*)—first, *seminare*, *to sow;* next, *extendere*, *to extend or spread* (as spun threads;) and lastly, what is here most important, *to radiate light* and *to shine* (as stars and fire). From this series of ideas we may deduce the names of the divinities, *Satis* (the female archer); *Sothis*, the radiating, and *Seth*, the fiery. We may also hieroglyphically explain *sit* or *seti*, the arrows as well as the ray; *seta*, to spin; *setu*, scattered seeds. *Sothis* is especially the *brightly radiating*, the star regulating the seasons of the year and periods of time. The small triangle, always represented yellow, which is a symbolical sign for Sothis, is used to designate the radiating sun when arranged in numerous triple rows issuing

Besides Sirius, Vega, Deneb, Regulus, and Spica, are at the present time decidedly white; and among the small double

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in a downward direction from the sun's disk. *Seth* is the fiery scorching god, in contradistinction to the warming, fructifying water of the Nile, the goddess *Satis* who inundates the soil. She is also the goddess of the cataracts, because the overflowing of the Nile began with the appearance of Sothis in the heavens at the summer solstice. In Vettius Valens the star itself is called Σὴθ instead of Sothis; but neither the name nor the subject admits of our identifying *Thoth* with Seth or Sothis, as Ideler has done. (*Handbuch der Chronologie*, bd. i. s. 126.)" (Lepsius, bd. i. s. 136.)

I will close these observations taken from the early Egyptian periods with some Hellenic, Zend, and Sanscrit etymologies: "Σείρ, the sun," says Professor Franz, "is an old root, differing only in pronunciation from θερ, θέρος, *heat*, *summer*, in which we meet with the same change in the vowel sound as in τεῖρος and τέρος or τέρας. The correctness of these assigned relations of the radicals σεὶρ and θερ, θέρος, is proved not only by the employment of θερείτατος in Aratus, v. 149 (Ideler, *Sternnamen*, s. 241), but also by the later use of the forms σεὶρος, σειριὸς, and σειρινός *hot*, *burning*, derived from σεὶρ. It is worthy of notice that σειρὰ or θειρινὰ ἱμάτια is used the same as θερινὰ ἱμάτια, *light summer clothing*. The form σέιριος seems, however, to have had a wider application; for it constitutes the ordinary term appended to all stars influencing the summer heat: hence, according to the version of the poet, Archilochus, the sun was σείριος άστὴρ, while Ibycus calls the stars generally σείρια, *luminous*. It cannot be doubted that it is the sun to which Archilochus refers in the words, πολλοὺς μὲν αὐτοῦ σείριος καταυανεῖ ὀξὺς ἐλλάμπων. According to Hesychius and Suidas, Σείριος does indeed signify both the sun and the Dog-star; but I fully coincide with M. Martin, the new editor of Theon of Smyrna, in believing that the passage of Hesiod (*Opera et Dies*, v. 417,) refers to the sun, as maintained by Tzetzes and *Proclus*, and not to the Dog-star. From the adjective σείριος. which has established itself as the '*epitheton perpetuum*' of the Dog-star, we derive the verb σειριόν, which may be translated 'to sparkle.' Aratus, v. 331, says of Sirius, ὀξέα σειριάει, 'it sparkles strongly.' When standing alone, the word Σειρήν, the stars Struve enumerates about 300, in which both stars are white.[53] Procyon, Atair, the Pole Star, and more especially β Ursæ Min. have a more or less decided yellow light. We have already enumerated among the larger red or reddish

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Siren, has a totally different etymology; and your conjecture, that it has merely an accidental similarity of sound with the brightly shining star Sirius, is perfectly well-founded. The opinion of those who, according to Theon Smyrnæus (*Liber de Astronomia*, 1850, p. 202), derive Σειρήν from σειριάζειν (a moreover unaccredited form of σειριâν) is likewise entirely erroneous. While the motion of heat and light is implied by the expression σείριος, the radical of the word Σειρὴν represents the flowing tones of this phenomenon of nature. It appears to me probable, that Σειρὴν is connected with εἴρειν (Plato, *Cratyl.* 398 D, τὸ γὰρ εἴρειν λέγειν ἐστί,) in which the original sharp aspiration passed into a hissing sound." (From letters of Prof. Franz to me, January, 1850.)

The Greek Σείρ, the sun, easily admits, according to Bopp, "of being associated with the Sanscrit word *svar*, which does not indeed signify the sun itself, but the heavens, (as something shining.) The ordinary Sanscrit denomination for the sun is *sûrya*, a contraction of *svârya*, which is not used. The root *svar* signifies in general *to shine.* The Zend designation for the sun is *hvare*, with the *h* instead of the *s*. The Greek θερ, θέρος and θερμὸς comes from the Sanscrit word *gharma* (Nom. *gharmas*,) warmth, heat."

The acute editor of the Rigveda, Max Müller, observes, that "the special Indian astronomical name of the Dog-star, *Lubdhaka*, which signifies *a hunter*, when considered in reference to the neighbouring constellation Orion, seems to indicate an ancient Arian community of ideas regarding these groups of stars." He is moreover principally inclined "to derive Σείριος from the Veda word *sira* (whence the adjective *sairya*,) and the root *sri*, to go, to wander; so that the sun and the brightest of the stars, Sirius, were originally called wandering stars." (Compare also Pott, *Etymologische Forschungen*, 1833, s. 130.)

[53] Struve, *Stellarum compositarum Mensuræ micrometricæ*, 1837, p. lxxiv. et lxxxiii.

stars Betelgeux, Arcturus, Aldebaran, Antares, and Pollux. Rümker finds γ Crucis of a fine red colour, and my old friend, Captain Bérard, who is an admirable observer, wrote from Madagascar in 1847, that he had for some years seen α Crucis growing red. The star η Argûs, which has been rendered celebrated by Sir John Herschel's observations, and to which I shall soon refer more circumstantially, is undergoing a change in colour, as well as in intensity of light. In the year 1843, Mr. Mackay noticed at Calcutta that this star was similar in colour to Arcturus, and was therefore reddish yellow;[54] but in letters from Santiago de Chili, in Feb. 1850, Lieutenant Gilliss speaks of it as being of a darker colour than Mars. Sir John Herschel, at the conclusion of his *Observations at the Cape*, gives a list of seventy-six *ruby-coloured* small stars, of the 7th to the 9th magnitude, some of which appear in the telescope like drops of blood. The majority of the variable stars are also described as red and reddish,[55] the exceptions being Algol in Caput Medusæ, β Lyræ and ε Auriga, which have a *pure white* light. Mira Ceti, in which a periodical change of light was first recognized, has a strong reddish light;[56] but the variability observed in Algol and β Lyræ, proves that this red colour is not a necessary condition of a change of light, since many red stars are not variable. The faintest stars in which colours can be distinguished belong, according to Struve, to the 9th and 10th magnitudes. Blue stars were first mentioned by Mariotte,[57] 1686, in his *Traité des Couleurs*. The light of α Lyræ is bluish; and a smaller stellar mass of 3½ minutes in diameter in the southern hemisphere consists, according to Dunlop, of blue stars alone. Among the double stars there are many in which the principal star is white, and the companion blue; and some in which both stars have a blue light,[58] (as δ Serp. and 59 Androm.) Occasionally, as in the stellar swarm near κ of the Southern Cross, which was mistaken by Lacaille for a nebulous spot, more than a hundred variously-coloured red, green, blue, and bluish-green stars are so closely thronged together that they appear in a powerful telescope "like a superb piece of fancy jewellery." [59]

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[54] Sir John Herschel, *Observations at the Cape*, p. 34.

[55] Mädler's *Astronomie*, s. 436.

[56] *Cosmos*, vol. ii. p. 713.

[57] Arago, *Annuaire pour* 1842, p. 348.

The ancients believed they could recognize a remarkable symmetry in the arrangement of certain stars of the 1st magnitude. Thus their attention was especially directed to the four so-called *regal stars* which are situated at opposite points of the sphere, Aldebaran and Antares, Regulus and Fomalhaut. We find this regular arrangement, of which I have already elsewhere treated,[60] specially referred to in a late Roman writer, Julius Firmicus Maternus,[61] who belonged to the age of Constantine. The differences of right ascension in these regal stars, *stellæ regales*, are 11h. 57m. and 12h. 49m. The importance formerly attached to this subject is probably owing to opinions transmitted from the East, which gained a footing in the Roman empire under the Cæsars, together with a strong national predilection for astrology. The leg, or north star of the Great Bear, (the celebrated star of the Bull's leg in the astronomical representations of Dendera, and in the Egyptian *Book of the Dead*) is perhaps the star indicated in an obscure passage of Job (ch. ix. ver. 9), in which Arcturus, Orion, and the Pleiades are contrasted with "the chambers of the south," and in which the four quarters of the heavens in like manner are indicated by these four groups.[62]

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[58] Struve, *Stellæ comp.*, p. lxxxii.

[59] Sir John Herschel, *Observations at the Cape*, pp. 17, 102. ("*Nebulæ and Clusters*, No. 3435.")

[60] Humboldt, *Vues des Cordillères et Monumens des peuples indigènes de l'Amérique*, tom. ii. p. 55.

[61] *Julii Firmici Materni Astron.*, libri viii. Basil, 1551, lib. vi. cap. i. p. 150.

While a large and splendid portion of the southern heavens beyond stars having 53° S. Decl. were unknown in ancient times, and even in the earlier part of the middle ages, the knowledge of the southern hemisphere was gradually completed about a century before the invention and application of the telescope. At the time of Ptolemy there were visible on the horizon of Alexandria, the Altar, the feet of the Centaur, the Southern Cross, then included in the Centaur, and according to Pliny also called *Cæsaris Thronus*, in honour of Augustus,[63] and Canopus (Canobus) in Argo, which is called *Ptolemæon* by the scholiast to Germanicus.[64] In the catalogue of the Almagest, Achernar, a star of the 1st magnitude, the last in Eridanus, (Achir el-nahr, in Arabic,) is also given, although it was 9° below the horizon. A report of the

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[62] Lepsius, *Chronol. der Ægypter*, bd. i. s. 143. In the Hebrew text mention is made of *Asch*, the giant (Orion?), the many stars (the Pleiades, Gemut?) and "the Chambers of the South." The Septuagint gives: *ὁ ποιῶν Ἑλειάδα καὶ Ἓσπερον καὶ Ἀρκτοῦρον καὶ ταμεῖα νότου.*

The early English translators, like the Germans and Dutch, understood the first group referred to in the verse to signify the stars in the Great Bear. Thus we find in Coverdale's version, "He maketh the waynes of heaven, the Orions, the vii. stars and the secret places of the south."—Adam Clarke's *Commentary on the Old Testament.*—(Tr.)

[63] Ideler, *Sternnamen*, s. 295.

[64] Martianus Capella changes *Ptolemæon* into *Ptolemæus;* both names were devised by the flatterers at the court of the Egyptian sovereigns. Amerigo Vespucci thought he had seen three Canopi, one of which was quite dark (*fosco*), *Canopus ingens et niger* of the Latin translation: most probably one of the black coal-sacks. (Humboldt, *Examen crit. de la Géogr.* tom. v. pp. 227, 229.) In the above-named *Elem. chronol. et Astron.* by El Fergani (p. 100), it is stated that the Christian pilgrims used to call the *Sohel* of the Arabs (Canopus) the star of St. Catherine, because they had the gratification of observing it, and admiring it as a guiding star when they journeyed from Gaza to Mount Sinai. In a fine episode to the Ramayana, the oldest heroic poem of Indian antiquity, the

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stars in the vicinity of the South Pole are declared for a singular reason to have been more recently created than the northern. When Brahminical Indians were emigrating from the north-west to the countries around the Ganges, from the 30th degree of north latitude to the lands of the tropics, where they subjected the original inhabitants to their dominion, they saw unknown stars rising above the horizon as they advanced towards Ceylon. In accordance with ancient practice, they combined these stars into new constellations. A bold fiction represented the later-seen stars as having been subsequently created by the miraculous power of Visvamitra, who threatened "the ancient gods that he would overcome the northern hemisphere, with his more richly starred southern hemisphere." (A. W. von Schlegel, in the *Zeitschrift fur die Kunde des Morgenlandes*, bd. i. s. 240.) While this Indian myth figuratively depicts the astonishment excited in wandering nations by the aspect of a new heaven (as the celebrated Spanish poet, Garcilaso de la Vega, says of travellers, "they change at once their country and stars," *mudan de pays y de estrellas*,) we are powerfully reminded of the impression that must have been excited, even in the rudest nations, when, at a certain part of the earth's surface, they observed large, hitherto unseen stars appear in the horizon, as those in the feet of the Centaur, in the Southern Cross, in Eridanus or in Argo, whilst those with which they had been long familiar at home wholly disappeared. The fixed stars advance towards us, and again recede, owing to the precession of the equinoxes. We have already mentioned that the Southern Cross was 7° above the horizon, in the countries around the Baltic, 2900 years before our era; at a time, therefore, when the great pyramids had already existed five hundred years. (Compare *Cosmos*, pp. 139 and 660.) "Canopus, on the other hand, can never have been visible at Berlin, as its distance from the South Pole of the ecliptic amounts to only 14°. It would have required a distance of 1° more to bring it within the limits of visibility for our horizon."

existence of this star must therefore have reached Ptolemy through the medium of those who had made voyages to the southern parts of the Red Sea, or between Ocelis and the Malabar emporium, Muziris.[65] Though improvements in the art of navigation led Diego Cam, together with Martin Behaim, along the western coasts of Africa, as early as 1484, and carried Bartholomew Diaz in 1487, and Gama in 1497 (on his way to the East Indies), far beyond the equator, into the Antarctic Seas, as far as 35° south lat., the first special notice of the large stars and nebulous spots, the first description of the "Magellanic clouds" and the "coal-sacks," and even the fame of "the wonders of the heavens not seen in the Mediterranean," belong to the epoch of Vincenze Yañez Pinzon, Amerigo Vespucci, and Andrea Corsali, between 1500 and 1515. The distances of the stars of the southern hemisphere were measured at the close of the 16th and the beginning of the 17th century.[66]

Laws of relative density in the distribution of the fixed stars in the vault of heaven, first began to be recognized when Sir William Herschel, in the year 1785, conceived the happy idea of counting the number of stars which passed at different heights and in various directions over the field of view, of 15′ in diameter, of his twenty-feet reflecting telescope. Frequent reference has already been made in the present work to his laborious process of "gauging the heavens." The field of view each time embraced only $\frac{1}{833000}$th of the whole heavens; and it would therefore require, according to Struve, eighty-threee years to gauge the whole sphere by a similar process.[67] In investigations of the partial distribution of stars, we must specially consider the class of magnitude to which they photometrically belong. If we limit our attention to the bright stars of the first three or four classes of magnitudes, we shall find them distributed on the whole with tolerable uniformity,[68] although in the southern hemisphere, from ε Orionis to α Crucis, they are locally crowded together in a splendid zone in the direction of a great circle. The various opinions expressed by different travellers on the relative beauty of the northern and southern hemispheres, frequently, I believe, depends wholly on the circumstance, that some of these observers have visited the southern regions at a period of the year when the finest portion of the constellations culminate in the day-time. It follows, from the gaugings of the two Herschels in the northern and southern hemispheres, that the fixed stars from the 5th and 6th to the 10th and 15th magnitudes (particularly, therefore, telescopic stars) increase regularly in density as we approach the galactic circle (ὁ γαλαξίας κύκλος); and that there are therefore poles rich in stars, and others poor in stars, the latter being at right angles to the principal axis of the Milky Way. The density of the stellar light is at its minimum at the poles of the galactic circle; and it increases in all directions, at first slowly, and then rapidly, in proportion to the increased galactic polar distance.

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[65] *Cosmos*, vol. ii. pp. 538, 539.

[66] Olbers in Schumacher's *Jahrb. für* 1840, s. 249, and *Cosmos*, vol. i. p. 51.

[67] *Etudes d'Astr. stellaire*, note 74, p. 31.

By an ingenious and careful consideration of the results of the gauges already made, Struve found that *on the average* there are 29·4 times (nearly 30 times) as many stars in the centre of the Milky Way as in regions surrounding the galactic poles. In northern galactic polar distances of 0°, 30°, 60°, 75°, and 90°, the relative numbers of the stars in a telescopic field of vision of 15′ diameter, are 4·15, 6·52, 17·68, 30·30, and 122·00. Notwithstanding the great similarity in the law of increase in the abundance of the stars, we again find in the comparison of these zones, an *absolute* preponderance[69] on the side of the more beautiful southern heavens.

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[68] *Outlines of Astr.*, § 785.

When in 1843 I requested Captain Schwinck (of the Engineers) to communicate to me the distribution according to right ascension of the 12148 stars (from the 1st to the 7th inclusive), which, at Bessel's suggestion, he had noted in his *Mappa cœlestis*, he found in four groups—

| | | | | |
|---|---|---|---|---|
| Right Ascension | 50° | to 140° | 3147 | stars. |
| „ | 140° | 230° | 2627 | „ |
| „ | 230° | 320° | 3523 | „ |
| „ | 320 | 50° | 2851 | „ |

These groups correspond with the more exact results of the *Etudes stellaires*, according to which the maxima of stars of the 1st to the 9th magnitude occur in the right ascension 6h. 40m. and 18h. 40m., and the minima in the right ascension of 1h. 30m. and 13h. 30m.[70]

It is essential that, in reference to the conjectural structure of the universe and to the position or depth of these strata of conglomerate matter, we should distinguish among the countless number of stars with which the heavens are studded, those which are scattered sporadically, and those which occur in separate, independent, and crowded groups. The latter are the so-called stellar *clusters* or *swarms*, which frequently contain thousands of telescopic stars in recognizable relations to each other, and which appear to the unaided eye as round nebulæ, shining like comets. These are, the nebulous stars of Eratosthenes[71] and Ptolemy, the *nebulosæ* of the Alphonsine Tables in 1483, and the same of which Galileo said in the *Nuncius sidereus*, "Sicut areolæ sparsim per æthera subfulgent."

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[69] *Op. cit.*, § 795, 796; Struve, *Etudes d'Astr. stell.* pp. 66, 73, (and note 75).

[70] Struve, p. 59. Schwinck finds in his maps, R. A. 0°—90°, 2858 stars; R. A. 90 — 180°, 3011 stars; R. A. 180 — 270°, 2688 stars; R. A. 270° — 360, 3591 stars; sum total, 12148, stars to the 7th magnitude.

These clusters of stars are either scattered separately throughout the heavens, or closely and irregularly crowded together, in strata, as it were, in the Milky Way, and in the Magellanic clouds. The greatest accumulation of globular clusters, and the most important in reference to the configuration of the galactic circle, occurs in a region of the southern heavens[72] between *Corona Australis*, *Sagittarius*, the tail of *Scorpio*, and the Altar. (R. A. 16h. 45m.–19h.) All clusters in and near the Milky Way are not, however, round and globular; there are many of irregular outline, with but few stars and not a very dense centre. In many globular clusters the stars are uniform in magnitude, in others they vary. In some few cases they exhibit a fine reddish central star.[73] (R. A. 2h. 10m.; N. Decl. 56° 21′.) It is a difficult problem in dynamics to understand how such island-worlds, with their multitude of suns, can rotate free and undisturbed. Nebulous spots and clusters of stars appear subject to different laws in their local distribution, although the former are now very generally assumed to consist of very small, and still more remote stars. The recognition of these laws must specially modify the conjectures entertained of what has been boldly termed the "structure of the heavens." It is moreover worthy of notice that, with an instrument of equal aperture and magnifying power, round nebulous spots are more easily resolved into clusters of stars than oval ones.[74]

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[71] On the nebula in the right hand of Perseus, (near the hilt of his sword,) see Eratosth. *Catast.*, c. 22, p. 51, Schaubach.

[72] John Herschel's *Observations at the Cape*, § 105, p. 136.

[73] *Outlines*, § 864–869, pp. 591–596; Mädler's *Astr.*, s. 764.

[74] *Observations at the Cape*, § 29, p. 19.

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I will content myself with naming the following among the isolated systems of clusters and swarms of stars.

The Pleiades: doubtless known to the rudest nations from the earliest times; the *mariner's stars*—Pleias, ἀπὸ τοῦ πλεῖν, (from πλεῖν, to sail,) according to the etymology of the old scholiast of Aratus, who is probably more correct than those modern writers, who would derive the name from πλέος, plenty. The navigation of the Mediterranean lasted from May to the beginning of November, from the early rising to the early setting of the Pleiades.

Præsepe in Cancer: according to Pliny, *nubecula quam Præsepia vocant inter Asellos*, a νεφέλιον of the Pseudo-Eratosthenes.

The cluster of stars on the sword-hilt of Perseus, frequently mentioned by Greek astronomers.

Coma Berenices, like the three former, visible to the naked eye.

A cluster of stars near Arcturus (No. 1663), telescopic: R. A. 13h. 34m. 12s., N. Decl. 29° 14′; more than a thousand stars from the 10th to the 12th magnitude.

Cluster of stars between η and ζ Herculis, visible to the naked eye in clear nights. A magnificent object in the telescope (No. 1968), with a singular radiating margin; R. A. 16h. 35m. 37s., N. Decl. 36° 47′; first described by Halley in 1714.

A cluster of stars near ω Centauri; described by Halley as early as 1677; appearing to the naked eye as a round cometic object, almost as bright as a star of the 4th or 5th magnitude; in powerful instruments it appears composed of countless stars of the 13th to the 15th magnitude, crowded together and most dense towards the centre; R. A. 13h. 16m. 38s., S. Decl. 46° 35′; No. 3504 in Sir John Herschel's catalogue of the clusters of the southern hemisphere, 15′ in diameter. (*Observations at the Cape*, pp. 21, 105; *Outlines of Astr.*, p. 595.)

Cluster of stars near κ of the Southern Cross (No. 3435), composed of many-coloured small stars from the 12th to the 16th magnitude, distributed over an area of $\frac{1}{48}$th of a square degree; a nebulous star, according to Lacaille, but so completely resolved by Sir John Herschel that no nebulous mass remained; the central star deep red. (*Observations at the Cape*, pp. 17, 102, pl. 1, fig. 2.)

Cluster of stars, 47 Toucani, Bode; No. 2322 of Sir John Herschel's catalogue, one of the most remarkable objects in the southern heavens. I was myself deceived by it for several evenings, imagining it to be a comet, when, on my arrival at Peru, I saw it in 12° south lat. rise high above the horizon. The visibility of this cluster to the naked eye is increased by the circumstance, that, although in the vicinity of the lesser Magellanic cloud, it is situated in a part of the heavens containing no stars, and is from 15′ to 20′ in diameter. It is of a pale rose colour in the interior, concentrically enclosed by a white margin composed of small stars (14th to 16th mag.) of about the same magnitude, and presenting all the characteristics of the globular form.[75]

A cluster of stars in Andromeda's girdle near ν of this constellation. The resolution of this celebrated nebula into small stars, upwards of 1500 of which have been recognized, appertains to the most remarkable discoveries in the observing astronomy of the present day. The merit of this discovery is due to Mr. Geo. Bond, assistant astronomer[76] at the Observatory of Cambridge, United States, (March,

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[75] "A stupendous object — a most magnificent *globular* cluster," says Sir John Herschel, "*completely insulated*, upon a ground of the sky perfectly *black* throughout the whole breadth of the sweep." *Observations at the Cape*, pp. 18 and 51, Pl. iii. fig. 1; *Outlines*, § 895, p. 615.

[76] Bond, in the *Memoirs of the American Academy of Arts and Sciences*, new series, vol. iii. p. 75.

1848,) and testifies to the admirable illuminating power of the refractor of that Observatory which has an object-glass fifteen inches in diameter; since even a reflector with a speculum of eighteen inches in diameter did not reveal "a trace of the presence of a star."[77] Although it is probable that the cluster in Andromeda was, at the close of the tenth century, already recorded as a nebula of oval form, it is more certain that Simon Marius (Mayer of Guntzenhausen), the same who first observed the change of colour in scintillation,[78] perceived it on the 15th of December, 1612; and that he was the first who described it circumstantially, as a new starless and wonderful cosmical body, unknown to Tycho Brahe. Half a century later, Boulliaud, the author of *Astronomia philolaica*, occupied himself with the same subject. This cluster of stars which is 2½° in length and more than 1° in breadth, is specially distinguished by two remarkable very narrow black streaks, parallel to each other, and to the longer axis of the cluster, which, according to Bond's investigations, traverse the whole length like fissures. This configuration vividly reminds us of the singular longitudinal fissure, in an unresolved nebula of the southern hemisphere, No. 3501, which has been described and figured by Sir John Herschel. (*Observations at the Cape*, pp. 20, 105, pl. iv. fig. 2.)

Notwithstanding the important discoveries for which we are indebted to Lord Rosse and his colossal telescope, I have not included the great nebula in Orion's belt in this selection of remarkable clusters of stars, as it appeared to me more appropriate to consider those portions of it which have been resolved, in the section on Nebulæ.

The greatest accumulation of clusters of stars, although by no means of nebulæ, occurs in the Milky Way,[79] (*Galaxias*, the celestial river of the Arabs,[80]) which forms almost a great circle of the sphere, and is inclined to the equator at an angle of 63°. The poles of the Milky Way are situated in Right Ascension 12h. 47m. N. Decl. 27°; and R. A. 0h. 47m. S. Decl. 27°; the south galactic pole therefore lies near Coma Berenices, and the northern between Phœnix and Cetus. While all planetary local relations are referred to the ecliptic,—the great circle in which the plane of the sun's path intersects the sphere—we may as conveniently refer many of the local relations of the fixed stars, as, for instance, that of their accumulation or grouping, to the nearly complete circle of the Milky Way. Considered in this light, the latter is to the sidereal world what the ecliptic is to the planetary

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[77] *Outlines*, § 874, p. 601.

[78] Delambre, *Hist. de l'Astr. moderne*, t. i. p. 697.

[79] We are indebted for the first and only complete description

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of the Milky Way, in both hemispheres, to Sir John Herschel, in his *Results of Astronomical Observations, made during the years* 1834–1838, *at the Cape of Good Hope*, § 316–335, and still more recently in the *Outlines of Astronomy*, § 787–799. Throughout the whole of that section of the *Cosmos* which treats of the directions, ramifications, and various contents of the Milky Way, I have exclusively followed the above named Astronomer and Physicist. (Compare also Struve, *Etudes d'Astr. stellaire*, pp. 35–79; Mädler, *Ast.*, 1849, § 213; *Cosmos*, vol. i. pp. 88, 140, and 305.) I need scarcely here remark that in my description of the Milky Way, in order not to confuse certainties with uncertainties, I have not referred to what I had myself observed with instruments of a very inferior illuminating power, in reference to the very great inequality of the light of the whole zone, during my long residence in the southern hemisphere, and which I have recorded in my journals.

[80] The comparison of the ramified Milky Way with a celestial river, led the Arabs to designate parts of the constellation of Sagittarius, whose bow falls in a region rich in stars, as *the cattle going to drink*, and to associate with them the ostrich, which has so little need of water. (Ideler, *Untersuchungen über den Ursprung und die Bedeutung der Sternnamen*, § 78, 183, and 187; Niebuhr, *Beschreibung von Arabien*, s. 112.)

world of our solar system. The Milky Way cuts the equator in Monoceros, between Procyon and Sirius, R. A. 6h. 54m., (for 1800), and in the left hand of Antinous, R. A. 19h. 15m. The Milky Way, therefore, divides the celestial sphere into two somewhat unequal halves, whose areas are nearly as 8 to 9. In the smaller portion lies the vernal solstice. The Milky Way varies considerably in breadth in different parts of its course.[81] At its narrowest, and at the same time most brilliant, portion, between the prow of Argo and the Cross, and nearest to the Antarctic pole, its width is scarcely 3° or 4°; at other parts it is 16°, and in its divided portion, between Ophiuchus and Antinous, as much as 22.° William Herschel has observed, that judging from his star-gaugings, the Milky Way would appear in many regions to have 6° or 7° greater width than we should be disposed to ascribe to it from the extent of stellar brightness visible to the naked eye.[83]

Huygens, who examined the Milky Way with his twenty-three feet refractor, declared, as early as the year 1656, that the milky whiteness of the whole Galactic zone was not to be ascribed to irresolvable nebulosity. A more careful application of reflecting telescopes of great dimensions and power of light has since proved, with more certainty, the correctness of the conjectures advanced by Democritus and Manilius, in reference to the ancient path of Phaëton, that this *milky* glimmering light was solely owing to the accumulated strata of small stars, and not to the scantily interspersed nebulæ. This effusion of light is the same at points, where the whole can be perfectly resolved into stars, and even in stars which are projected on a black ground, wholly free from nebulous vapour.[84] It is a remarkable feature of the Milky

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[81] *Outlines*, p. 529; Schubert, *Ast.*, th. iii. s. 71.

[82] Struve, *Etudes d'Astr. stellaire*, p. 41.

[83] *Cosmos*, vol. i. p. 140.

[84] "Stars standing on a clear black ground." (*Observations*

Way, that it should so rarely exhibit any globular clusters and nebulous spots of a regular or oval form;[85] while both are met with in great numbers at a remote distance from it; as, for instance, in the Magellanic clouds, where isolated stars, globular clusters in all conditions of condensation, and nebulous spots of a definite oval or a wholly irregular form, are intermingled. A remarkable exception to the rarity of globular clusters in the Milky Way, occurs in a region between R. A. 16h. 45m. and 18h. 44m. between the Altar, the Southern Crown, the head and body of Sagittarius, and the tail of the Scorpion.[86] We even find between ι and θ of the latter one of those annular nebulæ, which are of such extremely rare occurrence in the southern hemisphere.

In the field of view of powerful telescopes (and we must remember that, according to the calculations of Sir William

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*at the Cape*, p. 391). "This remarkable belt (the Milky Way, when examined through powerful telescopes) is found (wonderful to relate!) *to consist entirely of stars scattered by millions*, like glittering dust on the *black ground* of the general heavens." *Outlines*, pp. 182, 537, and 539.

[85] "*Globular clusters*, excepting in one region of small extent (between 16h. 45m. and 19h. in R. A.) and *nebulæ of regular elliptic forms*, are comparatively rare in the Milky Way, and are found congregated in the greatest abundance in a part of the heavens the most remote possible from that circle." (*Outlines*, p. 614.) Hugyens himself, as early as 1656, had remarked the absence of nebulosity and of all nebulous spots in the Milky Way. In the same place where he mentions the first discovery and delineation of the great nebulous spots in the belt of Orion, by a twenty-eight-feet refractor (1656), he says (as I have already remarked at p. 713 and note), *viam lacteam perspicillis inspectam nullas habere nebulas*, and that the Milky Way, like all that has been regarded as nebulous stars, is a great cluster of stars. The passage is to be found in *Hugenii Opera varia*, 1724, p. 593.

[86] *Observations at the Cape*, § 105, 107, and 328. On the annular nebulæ, No. 3686, see p. 114.

Herschel, a twenty-feet instrument penetrates 900, and a forty-feet one 2800 distances of Sirius) the Milky Way appears as diversified in its sidereal contents as it is irregular and indefinite in its outlines and limits when seen by the unaided eye. While in some parts the Milky Way exhibits, throughout a large space, the greatest uniformity in the light and apparent magnitudes of the stars, in others the most brilliant patches of closely-crowded luminous points are interrupted by granular or reticular darker[87] intervals containing but few stars; and in some of these intervals in the interior of the Galaxy not the smallest star (of the 18m. or 20m.) is to be discovered. It almost seems as though, in these regions, we actually saw through the whole starry stratum of the Milky Way. In gauging with a field of view of 15′ diameter, fields presenting on an average forty or fifty stars are almost immediately succeeded by others exhibiting from 400 to 500. Stars of the higher magnitudes often occur in the midst of the most minute telescopic stars, whilst all the intermediate classes are absent. Perhaps those stars which we regard as belonging to the lowest order of magnitudes do not always appear as such, solely on account of their enormous distance, but also because they actually have a smaller volume and less considerable development of light.

In order rightly to comprehend the contrast presented by the greater brilliancy, abundance, or paucity of stars, it will be necessary to compare regions most widely separated from each other. The maximum of the accumulation and the greatest lustre of stars are to be found between the prow of Argo and Sagittarius, or, to speak more exactly, between the Altar, the tail of the Scorpion, the hand and bow of Sagittarius, and the right foot of Ophiuchus. "No region of the heavens is fuller of objects, beautiful and remarkable in themselves, and rendered still more so by their mode of association" and grouping.[88] Next in brightness to this portion of the southern heavens is the pleasing and richly-starred region of our northern hemisphere in Aquila and Cygnus, where the Milky Way branches off in different directions. While the Milky Way is the narrowest under the foot of the Cross, the region of minimum brightness (where there is the greatest paucity of stars in the Galactic zone) is in the neighbourhood of Monoceros and Perseus.

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[87] "Intervals absolutely dark *and completely void of any star* of the smallest telescopic magnitude." *Outlines*, p. 536.

The magnificent effulgence of the Milky Way in the southern hemisphere is still further increased by the circumstance, that between the star η Argûs, which has become so celebrated in consequence of its variability, and α Crucis, under the parallels of 59° and 60° south lat., it is intersected at an angle of 20° by the remarkable zone of very large and probably very proximate stars, to which belong the constellations Orion, Canis Major, Scorpio, Centaurus, and the Southern Cross. The direction of this remarkable zone is indicated by a great circle passing through ε Orionis and the foot of the Cross. The picturesque effect of the Milky Way, if I may use the expression, is increased in both hemispheres by its various ramifications. It remains undivided for about two-fifths of its length. According to Sir John Herschel's observations the branches separate in the great bifurcation, at α Centauri,[89] and not at β Cent., as given in our maps of the stars, or, as was asserted by Ptolemy,[90] in the constellation of the Altar; they reunite again in Cygnus.

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[88] "No region of the heavens is fuller of objects, beautiful and remarkable in themselves, and rendered still more so by their mode of association, and by the peculiar features assumed by the Milky Way, which are without a parallel in any other part of its course." *Observations at the Cape*, p. 386. This vivid description of Sir John Herschel entirely coincides with the impressions I have myself experienced. Capt. Jacob, of the Bombay Engineers, in speaking of the intensity of light in the Milky Way, in the vicinity of the Southern Cross, remarks with striking truth, "Such is the general blaze of starlight near the Cross from that part of the sky, that a person is immediately made aware of its having risen above the horizon, though he should not be at the time looking at the heavens, by the increase of general illumination of the atmosphere, resembling the effect of the young moon." (See Piazzi Smyth, *On the orbit of α Centauri*, in the *Transact. of the Royal Soc. of Edinburgh*, vol. xvi. p. 445.)

In order to obtain a general insight into the whole course and direction of the Milky Way with its subdivisions, we will briefly consider its parts, following the order of their Right Ascension. Passing through γ and ε Cassiopeiæ, the Milky Way sends forth towards ε Persei a southern branch which loses itself in the direction of the Pleiades and Hyades. The main stream, which is here very faint, passes on through Auriga, over the three remarkable stars ε, ζ, η, the Hædi of that constellation, preceding Capella between the feet of Gemini and the horns of the Bull, (where it intersects the ecliptic nearly in the solstitial colure,) and thence over Orion's club to the neck of Monoceros, intersecting the equinoctial (in 1800) at R.A. 6h. 54m. From this point the brightness considerably increases. At the stern of Argo one branch runs southward to γ Argûs, where it terminates abruptly. The main stream is continued to 33° S. Decl., where, after separating in a fan-like shape (20° in breadth) it again breaks off, so that there is a wide gap in the Milky Way in the line from γ to λ Argûs. It begins again in a similar fan-like expansion, but contracts at the hind feet of the Centaur and before its entrance into the Southern Cross, where it is at its narrowest part, and is only 3° or 4° in width. Soon after this the Milky Way again expands into a bright and broad mass, which encloses $\beta$ Centauri as well as $\alpha$ and $\beta$ Crucis, and in the midst of which lies the black pear-shaped coal-sack, to which I shall more specially refer in the 7th section. In this remarkable region, somewhat below the coal-sack, the Milky Way approaches nearest to the South Pole.

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[89] *Outlines*, § 789, 791; *Observations at the Cape*, § 325.

[90] *Almagest*, lib. viii. cap. 2, (t. ii. pp. 84, 90, Halma). Ptolemy's description is admirable in some parts, especially when compared with Aristotle's treatment of the subject of the Milky Way, in *Meteor*. (lib. i. pp. 29, 34, according to Ideler's edition)

The above-mentioned bifurcation, which begins at $\alpha$ Centauri, extended, according to older views, to the constellation Cygnus. Passing from $\alpha$ Centauri, a narrow branch runs northwards in the direction of the constellation Lupus, where it seems gradually lost; a division next shows itself at $\gamma$ Normæ. The northern branch forms irregular outlines till it reaches the region of the foot of Ophiuchus, where it wholly disappears; the most southern branch then becomes the main-stream, and passes through the Altar and the tail of the Scorpion, in the direction of the bow of Sagittarius, where it intersects the ecliptic in 276° long. It next runs in an irregular patchy and winding stream through Aquila, Sagitta, and Vulpecula up to Cygnus; between $\epsilon$, $\alpha$, and $\gamma$, of which constellation a broad dark vacuity appears, which, as Sir John Herschel says, is not unlike the southern coal-sack, and serves as a kind of centre for the divergence of three great streams.[91] One of these, which is very vivid and conspicuous, may be traced running backward, as it were, through $\beta$ Cygni and $s$ Aquilæ, without, however, blending with the stream already noticed, which extends to the foot of Ophiuchus. A considerable offset or protuberant appendage is also thrown off by the northern stream from the head of Cepheus, and therefore near Cassiopeia, (from which constellation we began our description of the Milky Way) towards Ursa Minor and the pole.

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[91] *Outlines*, p. 531. The strikingly dark spot between $\alpha$ and $\gamma$ Cassiopeiæ is also ascribed to the contrast with the brightness by which it is surrounded. See Struve, *Etudes stell.*, note 58.

From the extraordinary advancement which the application of large telescopes has gradually effected in our knowledge of the sidereal contents and of the differences in the concentration of light observable in individual portions of the Milky Way, views of merely optical projection have been replaced by others referring rather to physical conformation. Thomas Wright of Durham,[92] Kant, Lambert, and at first also Sir William Herschel, were disposed to consider the form of the Milky Way, and the apparent accumulation of the stars within this zone, as a consequence of the flattened form and unequal dimensions of the *world-island* (starry stratum,) in which our solar system is included. The hypothesis of the uniform magnitude and distribution of the fixed stars has recently been attacked on many sides. The bold and gifted investigator of the heavens, Wm. Herschel, in his last works, expressed himself strongly in favour of the assumption of an annulus of stars; a view which he had contested in the talented treatise he composed in 1784. The most recent observations have favoured the hypothesis of a system of separate *concentric rings*. The thickness of these rings seems very unequal; and the different strata whose combined stronger or fainter light we receive, are undoubtedly situated at very different altitudes,

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[92] De Morgan has given an extract of the extremely rare work of Thomas Wright of Durham, (*Theory of the Universe*, London, 1750,) p. 241 in the *Philos. Magazine*, ser. iii. no. 32. Thomas Wright, to whose researches the attention of astronomers has been so permanently directed since the beginning of the present century, through the ingenious speculations of Kant and William Herschel, observed only with a reflector of one foot focal length.

[93] Pfaff, in *Will. Herschel's sämmtl. Schriften*, bd. i. (1826) s. 78–81; Struve, *Etudes stell.*, pp. 35–44.

*i. e.* at very unequal distances from us; but the relative brightness of the separate stars which we estimate as of the 10th to the 16th magnitude, cannot be regarded as affording sufficient data to enable us in a satisfactory manner to deduce numerically from them the radius of their spheres of distances.[94]

In many parts of the Milky Way the space-penetrating power of instruments is sufficient to resolve whole star-clouds, and to show the separate luminous points projected on the dark starless ground of the heavens. We here actually look through as into free space. "It leads us," says Sir John Herschel, "irresistibly to the conclusion that in these regions we see *fairly through* the starry stratum."[95] In other regions we see as it were through openings and fissures, remote world-islands, or outbranching portions of the annular system; in other parts, again, the Milky Way has hitherto been *fathomless*, even with the forty-feet telescope.[96] Investigations on the different intensity of light in the Milky Way, as well as on the magnitudes of the stars, which regularly increase in number from the galactic poles to the circle itself (an increase especially observable for 30° on either side of the Milky Way in stars below the 11th magnitude,[97] and therefore in $\frac{16}{17}$ of all the stars), have led the most recent investigator of the southern hemisphere to remarkable views and probable results in reference to the form of the galactic annular system, and what has been boldly called the *sun's place* in the world-island to which this annular system belongs. The place assigned to the sun is eccentric, and probably near a point where the stratum bifurcates or spreads itself out into two sheets,[98] in one of those desert regions lying nearer to the Southern Cross than to the opposite node of the Milky Way.[99] "The depth at which our system is plunged in the sidereal stratum, constituting the galaxy, reckoning from the southern surface or limit of that stratum, is about equal to that distance which on a general average corresponds to the light of a star of the 9th or 10th magnitude, and certainly does not exceed that corresponding to the 11th."[100] Where, from the peculiar nature of individual problems, measurements and the direct evidence of the senses fail, we see but dimly those results which intellectual contemplation, urged forward by an intuitive impulse, is ever striving to attain.

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[94] Encke, in Schumacher's *Astr. Nachr.*, no. 622, 1847, s. 341–346.

[95] *Outlines*, pp. 536, 537, where we find the following words on the same subject:—"In such cases it is equally impossible not to perceive that we are looking *through* a sheet of stars nearly of a size, and of no great thickness compared with the distance which separates them from us."

[96] Struve, *Etudes stell.*, p. 63. Sometimes the largest instruments reach a portion of the heavens, in which the existence of a starry stratum, shining at a remote distance, is only announced by "an uniform dotting or stippling of the field of view." See, in *Observations at the Cape*, p. 390, the section "On some indications of very remote telescopic branches of the Milky Way, or of an independent sidereal system or systems bearing a resemblance to such branches."

[97] *Observations at the Cape*, § 314.

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[98] Sir William Herschel, in the *Philos. Transact. for* 1785, p. 21; Sir John Herschel, *Observations at the Cape*, § 293. Compare also Struve, *Descr. de l'Observatoire de Poulkova*, 1845, pp. 267–271.

[99] "I think," says Sir John Herschel, "it is impossible to view this splendid zone from *a Centauri* to the Cross without an impression amounting almost to conviction, that the Milky Way is not a mere stratum, but annular; or, at least, that our system is placed within one of the poorer or almost vacant parts of its general mass, and that eccentrically, so as to be much nearer to the region about the Cross than to that diametrically opposite to it." (Mary Somerville, *On the Connexion of the Physical Sciences*, 1846, p. 419.)

[100] *Observations at the Cape*, § 315.

## IV.

### NEW STARS AND STARS THAT HAVE VANISHED.—VARIABLE STARS, WHOSE RECURRING PERIODS HAVE BEEN DETERMINED.—VARIATIONS IN THE INTENSITY OF THE LIGHT OF STARS WHOSE PERIODICITY IS AS YET UNINVESTIGATED.

New Stars.—The appearance of hitherto unseen stars in the vault of heaven, especially the sudden appearance of strongly scintillating stars of the first magnitude, is an occurrence in the realms of space which has ever excited astonishment. This astonishment is the greater, in proportion as such an event as the sudden manifestation of what was before invisible, but which nevertheless is supposed to have previously existed, is one of the very rarest phenomena in nature. While in the three centuries from 1500 to 1800, as many as forty-two comets, visible to the naked eye, have appeared to the inhabitants of the northern hemisphere—on an average, fourteen in every hundred years—only eight new stars have been observed throughout the same period. The rarity of the latter becomes still more striking, when we extend our consideration to yet longer periods. From the completion of the Alphonsine tables, an important epoch in the history of astronomy, down to the time of William Herschel—that is, from 1252 to 1800—the number of *visible* comets is estimated at about sixty-three, while that of new stars does not amount to more than nine. Consequently, for the period during which, in the civilized countries of Europe, we may depend on possessing a tolerably correct enumeration of both, the proportion of new stars to comets visible to the naked eye is as one to seven. We shall presently show that if from the tail-less comets we separate the new stars which, according to the records of Ma-tuan-lin, have been observed in China, and go back to the middle of the second century before the Christian era, that for about 2000 years scarcely more than twenty or twenty-two of such phenomena can be adduced with certainty.

Before I proceed to general considerations, it seems not inappropriate to quote the narrative of an eye-witness, and by dwelling on a particular instance to depict the vividness of the impression produced by the sight of a new star. "On my return to the Danish islands, from my travels in Germany," says Tycho Brahe, "I resided for some time with my uncle, Steno Bille (ut aulicæ vitæ fastidium lenirem), in the old and pleasantly situated monastery of Herritzwadt; and here I made it a practice not to leave my chemical laboratory until the evening. Raising my eyes, as usual, during one of my walks, to the well-known vault of heaven, I observed, with indescribable astonishment, near the zenith, in Cassiopeia, a radiant fixed star, of a magnitude never before seen. In my amazement, I doubted the evidence of my senses. However, to convince myself that it was no illusion, and to have the testimony of others, I summoned my assistants from the laboratory, and inquired of them, and of all the country people that passed by, if they also observed the star that had thus suddenly burst forth. I subsequently heard that, in Germany, waggoners and other common people first called the attention of astronomers to this great phenomenon in the heavens—a circumstance which, as in the case of non-predicted comets, furnished fresh occasion for the usual raillery at the expense of the learned.

"This new star," Tycho Brahe continues, "I found to be without a tail, not surrounded by any nebula, and perfectly like all other fixed stars, with the exception that it scintillated more strongly than stars of the first magnitude. Its brightness was greater than that of Sirius, α Lyræ, or Jupiter. For splendour, it was only comparable to Venus when nearest to the earth (that is, when only a quarter of her disc is illuminated). Those gifted with keen sight could, when the air was clear, discern the new star in the day-time, and even at noon. At night, when the sky was overcast, so that all other stars were hidden, it was often visible through the clouds, if they were not very dense (nubes non admodum densas). Its distances from the nearest stars of Cassiopeia, which throughout the whole of the following year I measured with great care, convinced me of its perfect immobility. Already, in December, 1572, its brilliancy began to diminish, and the star gradually resembled Jupiter; but by January, 1573, it had become less bright than that planet. Successive photometric estimates gave the following results: for February and March, equality with stars of the first magnitude (stellarum affixarum primi honoris—for Tycho Brahe seems to have disliked using Manilius's expression of stellæ fixæ); for April and May, with stars of the second magnitude; for July and August, with those of the third; for October and November, those of the fourth magnitude. Towards the month of November, the new star was not brighter than the eleventh in the lower part of Cassiopeia's chair. The transition to the fifth and sixth magnitude took place between December, 1573, and February, 1574. In the following month, the new star disappeared, and, after having shone seventeen months, was no longer discernible to the naked eye." (The telescope was not invented until thirty-seven years afterwards.)

The gradual diminution of the star's luminosity was moreover invariably regular; it was not (as is the case in the present day with η Argûs, though indeed that is not to be called a *new* star) interrupted by several periods of re-kindling or by increased intensity of light. Its colour also changed with its brightness (a fact which subsequently gave rise to many erroneous conclusions as to the velocity of coloured rays in their passage through space). At its first appearance, as long as it had the brilliancy of Venus and Jupiter, it was for two months white, and then it passed through yellow into red. In the spring of 1573, Tycho Brahe compared it to Mars; afterwards he thought that it nearly resembled Betelgeuze, the star in the right shoulder of Orion. Its colour for the most part was like the red tint of Aldebaran. In the spring of 1573, and especially in May, its white colour returned (albedinem quandam sublividam induebat, qualis Saturni stellæ subesse videtur). So it remained in January, 1574; being, up to the time of its entire disappearance in the month of March, 1574, of the fifth magnitude, and white, but of a duller whiteness, and exhibiting a remarkably strong scintillation in proportion to its faintness.

The circumstantial minuteness of these statements[1] is of itself a proof of the interest which this natural phenomenon could not fail to awaken, by calling forth many important questions, in an epoch so brilliant in the history of astronomy. For (notwithstanding the general rarity of the appearance of new stars) similar phenomena, accidentally crowded together within the short space of thirty-two years, were thrice repeated within the observation of European astronomers, and consequently served to heighten the excitement. The importance of star-catalogues, for ascertaining the date of the sudden appearance of any star, was more and more recognized; the periodicity[2] (their re-appearance after many centuries) was discussed; and Tycho Brahe himself boldly advanced a theory of the process by which stars might be formed and moulded out of cosmical vapour, which presents many points of resemblance to that of the great William Herschel. He was of opinion that the vapoury celestial matter which becomes luminous as it condenses, conglomerates into fixed stars: "Cœli materiam tenuissimam, ubique nostro visui et planetarum circuitibus perviam, in unum globum condensatam, stellam effingere." This celestial matter, which is universally dispersed through space, has already attained to a certain degree of condensation in the Milky Way, which glimmers with a soft silvery brightness. Accordingly, the place of the new star, as well as of those which became suddenly visible in 945 and 1264, was on the very edge of the Milky Way (quo factum est quod nova stella in ipso galaxiæ margine constiterit). Indeed, some went so far as to believe that they could discern the very spot (the opening or *hiatus*) whence the nebulous celestial matter had been drawn from the Milky Way.[3] All this reminds one of the theories of transition of the cosmical vapour into clusters of stars, of an agglomerative force, of a concentration to a central nucleus, and of hypotheses of a gradual formation of solid bodies out of a vaporous fluid;—views which were generally received in the beginning of the nineteenth century, but which at present, owing to the ever-changing fluctuations in the world of thought, are in many respects exposed to new doubts.

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[1] *De admiranda Nova Stella, anno* 1572, *exorta in Tychonis Brahe, Astronomiæ instauratæ Progymnasmata*, 1603, pp. 298–304, and 578. In the text I have closely followed the account which Tycho Brahe himself gives. The very doubtful statement (which is, however, repeated in several astronomical treatises) that his attention was first called to the phenomenon of the new star by a concourse of country people, need not therefore be here noticed.

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[2] Cardanus, in his controversy with Tycho Brahe, went back to the star of the Magi, which, as he pretended, was identical with the star of 1572. Ideler, arguing from his own calculations of the conjunctions of Saturn with Jupiter, and from similar conjectures advanced by Kepler on the appearance of the new star in Ophiuchus in 1604, supposes that *the star of the Magi*, through a confusion of ἀστὴρ with ἄστρον, which is so frequent, was not a single great star, but a remarkable conjunction of stars,—the close approximation of two brightly shining planets at a distance of less than a diameter of the moon. *Tychonis Progymnasmata*, pp. 324–330; contrast with Ideler, *Handbuch der mathematischen und technischen Chronologie*, bd. ii. s. 399–407.

[3] *Progymn.*, pp. 324–330. Tycho Brahe, in his theory of the formation of new stars from the *Cosmical vapour of the*

Among newly-appeared temporary stars the following (though with variable degrees of certainty) may be reckoned. I have arranged them according to the order in which they respectively appeared.

| | | | |
|---|---|---|---|
| (*a*) | 134 | B.C. | in Scorpio. |
| (*b*) | 123 | A.D. | in Ophiuchus. |
| (*c*) | 173 | „ | in Centaurus. |
| (*d*) | 369 | „ | ? |
| (*e*) | 386 | „ | in Sagittarius. |
| (*f*) | 389 | „ | in Aquila. |
| (*g*) | 393 | „ | in Scorpio. |
| (*h*) | 827 | „ | in Scorpio. |
| (*i*) | 945 | „ | between Cepheus and Cassiopeia. |
| (*k*) | 1012 | „ | in Aries. |
| (*l*) | 1203 | „ | in Scorpio. |
| (*m*) | 1230 | „ | in Ophiuchus. |
| (*n*) | 1264 | „ | between Cepheus and Cassiopeia. |
| (*o*) | 1572 | „ | in Cassiopeia. |
| (*p*) | 1578 | „ | |
| (*q*) | 1584 | „ | in Scorpio. |
| (*r*) | 1600 | „ | in Cygnus. |
| (*s*) | 1604 | „ | in Ophiuchus. |

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*Milky Way*, builds much on the remarkable passages of Aristotle on the connexion of the tails of comets (the vapoury radiation from their nuclei with the galaxy to which I have already alluded. (*Cosmos*, vol. i. p. 88.)

(*t*) 1609 „ . .
(*u*) 1670 „ . . in Vulpes.
(*v*) 1848 „ . . in Ophiuchus.

### EXPLANATORY REMARKS.

(*a*) This star first appeared in July, 134 years before our era. We have taken it from the Chinese Records of Ma-tuan-lin, for the translation of which we are indebted to the learned linguist Edward Biot (*Connaissance des Temps pour l'an* 1846, p. 61). Its place was between $\beta$ and $\rho$ of Scorpio. Among the *extraordinary* foreign-looking stars of these records, called also guest-stars, (*étoiles hôtes*, "Ke-sing," strangers of a singular aspect,) which are distinguished by the observers from comets with tails, fixed *new* stars and advancing tail-less comets are certainly sometimes mixed up. But in the record of their motion (Ke-sing of 1092, 1181, and 1458), and in the absence of any such record, as also in the occasional addition, "the Ke-sing dissolved" (disappeared), there is contained, if not an infallible, yet a very important criterion. Besides, we must bear in mind that the light of the nucleus of all comets, whether with or without tails, is dull, never scintillates, and exhibits only a mild radiance, while the luminous intensity of what the Chinese call extraordinary (stranger) stars, has been compared to that of Venus,—a circumstance totally at variance with the nature of comets in general, and especially of those without tails. The star which appeared in 134 B.C., under the old Han dynasty, may, as Sir John Herschel remarks, have been the new star of Hipparchus, which, according to the statement of Pliny, induced him to commence his catalogue of the stars. Delambre twice calls this statement a fiction, "une historiette." (*Hist. de l'Astr. anc.*, t. i. p. 290; and *Hist. de l'Astr. mod.*, t. i. p. 186.) Since, according to the express statement of Ptolemy (*Almag.* vii. p. 2, 13 *Halma*), the catalogue of Hipparchus belongs to the year 128 B.C., and Hipparchus (as I have already remarked elsewhere) carried on his observations in Rhodes (and perhaps also in Alexandria), from 162 to 127 B.C., there is nothing irreconcilable with this conjecture. It is very probable that the great Nicean astronomer had pursued his observations for a considerable period before he conceived the idea of forming a regular catalogue. The words of Pliny, "suo ævo genita," apply to the whole term of his life. After the appearance of Tycho Brahe's star in 1572, it was much disputed whether the star of Hipparchus ought to be classed among *new* stars, or comets without tails. Tycho Brahe himself was of the former opinion (*Progymn.*, pp. 319–325). The words "ejusque motu addubitationem adductus," may undoubtedly lead to the supposition of a faint, or altogether tail-less comet; but Pliny's rhetorical style admitted of such vagueness of expression.

(*b*) A Chinese observation. It appeared in December, A.D. 123, between α Herculis and α Ophiuchi. Ed. Biot, from Ma-tuan-lin. (It is also asserted that a new star appeared in the reign of Hadrian, about A.D. 130.)

(*c*) A singular and very large star. This also is taken from Ma-tuan-lin, as well as the three following ones.

It appeared on the 10th of December, 173, between α and β Centauri, and at the end of eight months disappeared, after exhibiting the five colours one after another. "*Successivement*" is the term employed by Ed. Biot in his translation. Such an expression would almost tend to suggest a series of colours similar to those in the above described star of Tycho Brahe; but Sir John Herschel more correctly takes it to mean a coloured scintillation (*Outlines*, p. 563), and Arago interprets in the same way a nearly similar expression employed by Kepler when speaking of the new star (1604) in Ophiuchus. (*Annuaire pour* 1842, p. 347.)

(*d*) This star was seen from March to August, 369.

(*e*) Between λ and φ Sagittarii. In the Chinese Record it is expressly observed, "where the star remained (*i. e.* without movement) from April to July, 386."

(*f*) A new star, close to α Aquilæ. In the year 389, in the reign of the Emperor Honorius, it shone forth with the brilliancy of Venus, according to the statement of Cuspinianus, who had himself seen it. It totally disappeared in about three weeks.[4]

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[4] Other accounts place the appearance in the year 388 or 398. Jacques Cassini, *Elémens d'Astronomie*, 1740 (*Etoile nouvelles*), p. 59.

(*g*) March, 393. This star was also in Scorpio, in the tail of that constellation. From the Records of Ma-tuan-lin.

(*h*) The precise year ( 827 ) is doubtful. It may with more certainty be assigned to the first half of the ninth century, when in the reign of Caliph Al Mamoun the two famous Arabian astronomers, Haly and Giafar Ben Mohammed Albumazar observed at Babylon a new star, whose light, according to their report, "equalled that of the moon in her quarters." This natural phenomenon likewise occurred in Scorpio. The star disappeared after a period of four months.

(*i*) The appearance of this star (which is said to have shone forth in the year 945, under Otho the Great), like that of 1264, is vouched for solely by the testimony of the Bohemian astronomer Cyprianus Leovitius, who asserts that he derived his statements concerning it from a manuscript chronicle. He also calls attention to the fact, that these two phenomena (that in 945 and that in 1264) took place between the constellations of Cepheus and Cassiopeia, close to the Milky Way, and near the spot where Tycho Brahe's star appeared in 1572. Tycho Brahe (*Progym.*, pp. 331 and 709) defends the credibility of Cyprianus Leovitius, against the attacks of Pontanus and Camerarius, who conjectured that the statements arose from a confusion of new stars with long-tailed comets.

(*k*) According to the statement of Hepidannus, the monk of St. Gall (who died A.D. 1088, whose annals extend from the year A.D. 709 to 1044), a new star of unusual magnitude and of a brilliancy that dazzled the eye (oculos verberans), was, for three months, from the end of May in the year 1012, to be seen in the south, in the constellation of Aries. In a most singular manner it appeared to vary in size, and occasionally it could not be seen at all. "Nova stella apparuit insolitæ magnitudinis, aspectu fulgurans et oculos verberans non sine terrore. Quæ mirum in modum aliquando contractior, aliquando diffusior, etiam extinguebatur interdum. Visa est autem per tres menses in intimis finibus Austri, ultra omnia signa quæ videntur in cœlo." (See Hepidanni *Annales breves*, in Duchesne, *Historiæ Francorum Scriptores*, t. iii. 1641, p. 477. Compare also Schnurrer, *Chronik der Seuchen*, th. i. s. 201). To the manuscript made use of by Duchesne and Goldast, which assigns the phenomenon to the year 1012, modern historical criticism has, however, preferred another manuscript which, as compared with the former, exhibits many deviations in the dates, throwing them six years back. Thus, it places the appearance of this star in 1006. (See *Annalse Sangallenses majores*, in Pertz, *Monumenta Germaniæ historica Scriptorum*, t. i. 1826, p. 81.) Even the authenticity of the writings of Hepidannus has been called into question by modern critics. The singular phenomenon of variability has been termed by Chladni the *conflagration* and *extinction* of a fixed star. Hind (*Notices of the Astron. Soc.*, vol. viii. 1848, p. 156) conjectures that this star of Hepidannus is identical with a new star, which is recorded in Ma-tuan-lin, as having been seen in China, in February, 1011, between σ and φ of Sagittarius. But in that case there must be an error in Ma-tuan-lin, not only in the statement of the year, but also of the constellation in which the star appeared.

(*l*) Towards the end of July, 1203, in the tail of Scorpio. According to the Chinese Record, this new star was "of a bluish-white colour, without luminous vapour, and resembled Saturn." (Edouard Biot, in the *Connaissance des Temps pour* 1846, p. 68.)

(*m*) Another Chinese observation, from Ma-tuan-lin, whose astronomical records, containing an accurate account of the positions of comets and fixed stars, go back to the year 613 B.C., to the times of Thales and the expedition of Colæus of Samos. This new star appeared in the middle of December, 1230, between Ophiuchus and the Serpent. It dissolved towards the end of March, 1231.

(*n*) This is the star mentioned by the Bohemian astronomer, Cyprianus Leovitius (and referred to under the 9th star, in the year 945). About the same time (July, 1264), a great comet appeared, whose tail swept over one half of the heavens, and which, therefore, could not be mistaken for a new star suddenly appearing between Cepheus and Cassiopeia.

(*o*) This is Tycho Brahe's star of the 11th of November, 1572, in the Chair of Cassiopeia, R. A. 3° 26′; Decl. 63° 3′ (for 1800).

(*p*) February, 1578. Taken from Ma-tuan-lin. The constellation is not given, but the intensity and radiation of the light must have been extraordinary, since the Chinese Record appends the remark, "a star as large as the sun!"

($q$) On the 1st of July, 1584, not far from $\pi$ of Scorpio; also a Chinese observation.

($r$) According to Bayer, the star 34 of Cygnus. Wilhelm Jansen, the celebrated geographer, who for a time had been the associate of Tycho Brahe in his observations, was the first, as an inscription on his celestial globe testifies, to draw attention to the new star in the breast of the Swan, near the beginning of the neck. Kepler, who, after the death of Tycho Brahe, was for some time prevented from carrying on any observations, both by his travels and want of instruments, did not observe it till two years later, and indeed (what is the more surprising, since the star was of the 3rd magnitude) then first heard of its existence. He thus writes:—"Cum mense Maio, anni 1602, primum litteris monerer de novo Cygni phænomeno." (Kepler, *De Stella nova tertii honoris in Cygno*, 1606, which is appended to the work *De Stella nova in Serpent.*, pp. 152, 154, 164, and 167.) In Kepler's treatise it is nowhere said (as we often find asserted in modern works) that this star of Cygnus upon its first appearance was of the 1st magnitude. Kepler even calls it "parva Cygni stella," and speaks of it throughout as one of the 3rd magnitude. He determines its position in R. A. 300° 46′; Decl. 36° 52′ (therefore for 1800: R. A. 302° 36′; Decl. + 37° 27′). The star decreased in brilliancy, especially after the year 1619, and vanished in 1621. Dominique Cassini (see Jacques Cassini, *Elémens d'Astr.*, p. 69) saw it, in 1655, again attain to the 3rd magnitude, and then disappear. Hevelius observed it again in November, 1665, at first extremely small, then larger, but never attaining to the 3rd magnitude. Between 1677 and 1682 it decreased to the 6th magnitude, and as such it has remained in the heavens. Sir John Herschel classes it among the variable stars, in which he differs from Argelander.

($s$) After the star of 1572 in Cassiopeia, the most famous of the *new* stars is that of 1604 in Ophiuchus (R. A. 259° 42′; and S. Decl. 21° 15′, for 1800). With each of these stars a great name is associated. The star in the right foot of Ophiuchus was originally discovered, on the 10th of October, 1604, not by Kepler himself, but by his pupil, the Bohemian astronomer, John Bronowski. It was larger than all stars of the first order, greater than Jupiter and Saturn, but smaller than Venus. Herlicius asserts that he had previously seen it on the 27th of September. Its brilliancy was less than that of the new star, discovered by Tycho Brahe in 1572. Moreover, unlike the latter, it was not discernible in the daytime. But its scintillation was considerably greater, and especially excited the astonishment of all who saw it. As scintillation is always accompanied with dispersion of colour, much has been said of its coloured, and continually changing light. Arago (*Annuaire pour* 1834, pp. 299–301, and *Ann. pour* 1842, pp. 345–347) has already called attention to the fact that the star of Kepler did not by any means, like that of Tycho Brahe, assume, at certain long intervals, different colours, such as yellow, red, and then again white. Kepler says expressly that his star, as soon as it rose above the exhalations of the earth, was white. When he speaks of the colours of the rainbow, it is to convey a clear idea of its coloured scintillation. His words are: "Exemplo adamantis multanguli, qui solis radios inter convertendum ad spectantium oculos variabili fulgore revibraret, colores Iridis (stella nova in Ophiucho) successive vibratu *continuo* reciprocabat." (*De nova Stella Serpent.*, pp. 5 and 125.) In the beginning of January, 1605, this star was even brighter than Antares, but less luminous than Arcturus. By the end of March in the same year, it was described as being of the 3rd magnitude. Its proximity to the sun prevented all observation for four months. Between February and March, 1606, it totally disappeared. The inaccurate statements as to the great variations in the position of the new star, advanced by Scipio Claramontius and the geographer Blaew, are scarcely (as Jacques Cassini, *Elémens d'Astr.*, p. 65, long since observed) deserving of notice, since they have been refuted by Kepler's more trustworthy treatise. The Chinese Record of Ma-tuan-lin mentions a phenomenon which exhibits some points of resemblance, as to time and position, with this sudden appearance of a new star in Ophiuchus. On the 30th of September, 1604, there was seen in China a reddish-yellow ("ball-like?") star, not far from π of Scorpio. It shone in the south-west till November of the same year, when it became invisible. It re-appeared on the 14th of January, 1605, in the south-east; but its light became slightly duller by March, 1606. (*Connaissance des Temps pour* 1846, p. 59.) The locality, $\pi$ of the Scorpion, might easily be confounded with the foot of Ophiuchus; but the expressions south-west and south-east. its re-appearance, and the circumstance that its ultimate total disappearance is not mentioned, leave some doubts as to its identity.

(*t*) This also is a new star of considerable magnitude and seen in the south-west. It is mentioned in Ma-tuan-lin. No further particulars are recorded.

(*u*) This is the new star discovered by the Carthusian monk Anthelmus on the 20th of June, 1670, in the head of Vulpes, (R. A. 294° 27′; Decl. 26° 47′,) and not far from $\beta$ Cygni. At its first appearance, it was not of the first, but merely of the 3rd magnitude, and on the 10th of August it diminished to the 5th. It disappeared after three months, but showed itself again on the 17th of March, 1671, when it was of the 4th magnitude. Dominique Cassini observed it very closely in April, 1671, and found its brightness very variable. The new star is reported to have regained its original splendour after ten months, but in February, 1672, it was looked for in vain. It did not re-appear until the 29th of March in the same year, and then only as a star of the 6th magnitude; since that time it has never been observed. (Jacques Cassini, *Elémens d'Astr.*, pp. 69–71.) These phenomena induced Dominique Cassini to search for stars never before seen (by him!). He maintained, that he had discovered fourteen such stars of the 4th, 5th, and 6th magnitudes, (eight in Cassiopeia, two in Eridanus, and four near the North Pole). From the absence of any precise data as to their respective positions, and especially since, like those said to have been discovered by Maraldi between 1694 and 1709, their existence is more than questionable, they cannot be introduced in our present list. (Jacques Cassini, *Elémens d'Astron.*, pp. 73–77; Delambre, *Hist. de l'Astr. mod.*, t. ii. p. 780).

(*v*) A hundred and seventy-eight years elapsed after the appearance of the new star in Vulpes without a similar phenomenon having occurred, although in this long interval the heavens were most carefully explored and its stars counted, by the aid of a more diligent use of telescopes and by comparison with more correct catalogues of the stars.

On the 28th of April, 1848, at Mr. Bishop's private observatory, (South Villa, Regent's Park,) Hind made the important discovery of a new reddish-yellow star of the 5th magnitude in Ophiuchus (R. A. 16° 50′ 59″; S. Decl. 12° 39′ 16″, for 1848). In the case of no other new star have the novelty of the phenomenon, and the invariability of its position, been demonstrated with greater precision. At the present time (1850) it is scarcely of the 11th magnitude, and according to Lichtenberger's accurate observations it will most likely soon disappear. (*Notices of the Astr. Soc.*, vol. viii. pp. 146 and 155–158.)

The above list of new stars, which within the last two thousand years have suddenly appeared and again disappeared, is probably more complete than any before given, and may justify a few general remarks. We may distinguish three classes: new stars which suddenly shine forth and then after a longer or shorter time disappear; stars whose brightness is subject to a periodical variability which has been already determined; and stars, like η Argûs, which suddenly exhibit an unusual increase of brilliancy, the variations of which are still undetermined. All these phenomena are, most probably, intrinsically related to each other. The new star in Cygnus (1600) which, after its total disappearance (at least to the naked eye) again appeared and continued as a star of the 6th magnitude, leads us to infer the affinity of the two first kinds of celestial phenomena. The celebrated star discovered by Tycho Brahe in Cassiopeia in 1572 was considered, even while it was still shining, to be identical with the new star of 945 and 1264. The period of 300 years which Goodricke conjectured, has been reduced by Keill and Pigott to 150 years. The *partial* intervals of the actual phenomena, which perhaps are not very numerically accurate, amount to 319 and 308 years. Arago[5] has pointed out the great improbability that Tycho Brahe's star of 1572 belongs to those which are periodically *variable*. Nothing as yet seems to justify us in regarding *all* new stars as variable in long periods, which from their very length have remained unknown to us. If, for instance, the self-luminosity of all the suns of the firmament is the result of an electro-magnetic process in their photospheres, we may consider this process of light as variable in many ways, without assuming any local or temporary *condensations of the celestial ether*, or any intervention of the so-called *cosmical clouds*. It may either occur only once or recur periodically, and either regularly or irregularly. The electrical processes of light on our earth, which manifest themselves either as thunder-storms in the regions of the air, or as polar effluxes, together with much apparently irregular variation, exhibit nevertheless a certain periodicity dependent both on the seasons of the year and the hours of the day; and this fact is, indeed, frequently observed in the formation for several consecutive days, during perfectly clear weather, of a small mass of clouds in particular regions of the sky, as is proved by the frequent failures in attempts to observe the culmination of stars.

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[5] Arago, *Annuaire pour* 1842, p. 332.

The circumstance that almost all these new stars burst forth at once with extreme brilliancy, as stars of the 1st magnitude, and even with still stronger scintillation, and that they do not appear, at least to the naked eye, to increase gradually in brightness, is, in my opinion, a singular peculiarity, and one well deserving of consideration. Kepler[6] attached such weight to this criterion, that he refuted the idle pretension of Antonius Laurentinus Politianus, to having seen the star in Ophiuchus (1604) before Bronowski, simply by the circumstance that Laurentinus had said—"Apparuit nova stella parva et postea de die in diem crescendo apparuit lumine non multo inferior Venere, superior Jove." There are only three stars which may be looked upon in the light of exceptions, that did not shine forth at once as of the 1st magnitude; viz. the star which appeared in Cygnus in 1600, and that in Vulpes in 1670, which were both of the 3rd, and Hind's new star in Ophiuchus in 1848, which is of the 5th magnitude.

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[6] Kepler, *De Stella nova in pede Serp.*, p. 3.

It is much to be regretted, as we have already observed, that after the invention of the telescope in the long period of 178 years, only two new stars have been seen, whereas these phenomena have sometimes occurred in such rapid succession, that at the end of the fourth century four were observed in twenty-four years; in the thirteenth century, three in sixty-one years; and during the era of Tycho Brahe and Kepler at the end of the sixteenth and beginning of the seventeenth centuries, no less than six were observed within a period of thirty-seven years. Throughout this examination I have kept in view the Chinese observations of *extraordinary* stars, most of which, according to the opinion of the most eminent astronomers, are deserving of our confidence. Why it is that of the new stars seen in Europe, that of Kepler in Ophiuchus (1604) is in all probability recorded in the records of Ma-tuan-lin, while that of Tycho in Cassiopeia (1572) is not noticed, I for my part am as little able to explain as I am to account for the fact, that no mention was made in the sixteenth century, among European astronomers, of the great luminous phenomenon which was observed in China in February, 1578. The difference of longitude (114°) could only in a few instances account for their not being visible. Whoever has been engaged in such investigations, must be well aware that the want of record either of political events or natural phenomena, either upon the earth or in the heavens, is not invariably a proof of their never having taken place; and on comparing together the three different catalogues which are given in Ma-tuan-lin, we actually find comets (those for instance of 1385 and 1495), mentioned in one but omitted in the others.

Even the earlier astronomers (Tycho Brahe and Kepler), as well as the more modern (Sir John Herschel and Hind) have called attention to the fact that the great majority (four-fifths, I make it) of all the new stars described both in Europe and China, have appeared in the neighbourhood of or within the Milky Way. If that which gives so mild and nebulous a light to the annular starry strata of the Milky Way is, as is more than probable, a mere aggregation of small telescopic stars, Tycho Brahe's hypothesis, which we have already mentioned, of the formation of new, suddenly-shining fixed stars, by the globular condensation of celestial vapour, falls at once to the ground. What the influence of gravitation may be among the crowded strata and clusters of stars, supposing them to revolve round certain central nuclei, is a question not to be here determined, and belongs to the mythical part of Astrognosy. Of the twenty-one new stars enumerated in the above list, five (those of 134, 393, 827, 1203, and 1584) appeared in Scorpio, three in Cassiopeia and Cepheus (945, 1264, 1572), and four in Ophiuchus (123, 1230, 1604, 1848). Once, however (1012), one was seen in Aries at a great distance from the Milky Way (the star seen by the monk of St. Gall). Kepler himself, who however considers as a new star that described by Fabricius, as suddenly shining in the neck of Cetus in the year 1596, and as disappearing in October of the same year, likewise advances this position as a proof to the contrary. (Kepler, *De Stella Nova Serp.*, p. 112.) Is it allowable to infer, from the frequent lighting up of such stars in the same constellations, that in certain regions of space—those, namely, where Cassiopeia and Scorpio are to be seen—the conditions of their illuminations are favoured by certain local relations? Do such stars as are peculiarly fitted for the explosive temporary processes of light, especially lie in those directions?

The stars whose luminosity was of the shortest duration, were those of 389, 827, and 1012. In the first of the abovenamed years, the luminosity continued only for three weeks; in the second, four months; in the third, three. On the other hand, Tycho Brahe's star in Cassiopeia continued to shine for seventeen months; while Kepler's star in Cygnus (1600) was visible fully twenty-one years before it totally disappeared. It was again seen in 1655, and still of the 3rd magnitude, as at its first appearance, and afterwards dwindled down to the 6th magnitude, without, however (according to Argelander's observations), being entitled to rank among periodically variable stars.

STARS THAT HAVE DISAPPEARED.—The observation and enumeration of stars that have disappeared is of importance for discovering the great number of small planets which probably belong to our solar system. Notwithstanding, however, the great accuracy of the catalogued positions of telescopic fixed stars and of modern star-maps, the certainty of conviction that a star in the heavens has actually disappeared since a certain epoch can only be arrived at with great caution. Errors of actual observation, of reduction, and of the press,[7] often disfigure the very best catalogues. The disappearance of a heavenly body from the place in which it had before been distinctly seen, may be the result of its own motion as much as of any such diminution of its photometric process (whether on its surface or in its photosphere), as would render the waves of light too weak to excite our organs of sight. What we no longer see, is not necessarily annihilated. The idea of destruction or combustion, as applied to disappearing stars, belongs to the age of Tycho Brahe. Even Pliny, in the fine passage where he is speaking of Hipparchus, makes it a question: Stellæ an obirent nascerenturve? The apparent eternal cosmical alternation of existence and destruction is not annihilation; it is merely the transition of matter into new forms, into combinations which are subject to new processes. *Dark cosmical bodies* may by a renewed process of light again become luminous.

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[7] On instances of stars which have not disappeared, see Argelander in Schumacher's *Astronom. Nachr.*, no. 624, s. 371. To adduce an example from antiquity, I may point to the fact that the carelessness with which Aratus compiled his poetical catalogue of the stars has led to the often-renewed question, whether Vega Lyræ is a new star or one which varies in long periods. For instance, Aratus asserts that the constellation of Lyra consists wholly of small stars. It is singular that Hipparchus, in his Commentary, does not notice this mistake, especially as he censures Aratus for his statements as to the relative intensity of light in the stars of Cassiopeia, and Ophiuchus. All this, however, is only accidental and not demonstrative; for when Ara-

PERIODICALLY VARIABLE STARS. — Since all is in motion in the vault of heaven, and everything is variable both in space and time, we are led by analogy to infer that as the fixed stars universally have not merely an apparent, but also a proper motion of their own, so their surfaces or luminous atmospheres are generally subject to those changes which recur, in the great majority, in extremely long

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tus also ascribes to Cygnus none but stars "of moderate brilliancy," Hipparchus expressly refutes this error, and adds the remark, that the bright star in the Swan (Deneb) is little inferior in brilliancy to Lyra (Vega Lyræ). Ptolemy classes Vega among stars of the 1st magnitude, and in the Catasterisms of Eratosthenes (cap. 25), Vega is called λευκὸν καὶ λαμπρὸν. Considering the many inaccuracies of a poet, who never himself observed the stars, one is not much disposed to give credit to the assertion that it was only between the years 272 and 127 B.C., *i.e.*, between the times of Aratus and Hipparchus, that the star Vega Lyræ (*Fidicula* of Pliny, xviii. 25,) became a star of the 1st magnitude.

and therefore *unmeasured* and probably *undeterminable* periods, or which, in a few, occur without being periodical, as it were, by a sudden revolution, either for a shorter or for a longer time. The latter class of phenomena (of which a remarkable instance is furnished in our own days by a large star in Argo) will not be here discussed, as our proper subject is those fixed stars whose *periods have already been investigated and ascertained.* It is of importance here to make a distinction between three great sidereal phenomena, whose connexion has not as yet been demonstrated; namely, variable stars of known periodicity; the instantaneous lighting up in the heavens of so-called *new* stars; and sudden changes in the luminosity of long-known fixed stars, which previously shone with uniform intensity. We shall first of all dwell exclusively on the first kind of variability; of this the earliest instance accurately *observed* is furnished (1638) by Mira, a star in the neck of Cetus. The East-Friesland pastor, David Fabricius (the father of the discoverer of the spots on the sun), had certainly already observed this star on the 13th of August, 1596, as of the 3rd magnitude, and in October of the same year he saw it disappear. But it was not until forty-two years afterwards that the alternating, recurring variability of its light, and its periodic changes, were discovered by the Professor Johann Phocylides Holwarda, Professor of Francker. This discovery was further followed in the same century by that of two other variable stars $\beta$ Persei (1669), described by Montanari, and $\chi$ Cygni (1687) by Kirch.

The irregularities which have been noticed in the periods, together with the additional number of stars of this class which have been discovered have, since the beginning of the nineteenth century, awakened the most lively interest in this complicated group of phenomena. From the difficulty of the subject, and from my own wish to be able to set down in the present work the *numerical elements* of this variability (as being the most important result of all observations), so far as in the present state of the science they have been ascertained, I have availed myself of the friendly aid of that astronomer who of all our contemporaries has devoted himself with the greatest diligence, and with the most brilliant success, to the study of the periodically varying stars. The doubts and questions called forth by my own labours I confidently laid before my worthy friend Argelander, the director of the Observatory at Bonn; and it is to his manuscript communications that I am solely indebted for all that follows, which for the most part has never before been published.

The greater number of the variable stars, although not all, are of a red or reddish colour. Thus, for instance, besides β Persei (Algol in the head of Medusa), β Lyræ and ε Aurigæ have also a white light. The star η Aquilæ is rather yellowish; so also in a still less degree is ζ Geminorum. The old assertion that some variable stars (and especially Mira Ceti) are redder when their brilliancy is on the wane than on the increase, seems to be groundless. Whether in the double star α Herculis (in which, according to Sir John Herschel, the greater star is red, but according to Struve yellow, while its companion is said to be dark blue) the small companion, estimated at between the 5th to the 7th magnitude, is itself also variable, appears very problematical. Struve[8] himself merely says. *Suspicor minorem esse variabilem.* Variability is by no means a necessary concomitant of redness. There are many red stars: some of them very red—as Arcturus and Aldebaran—in which, however, no variability has as yet been discovered. And it is also more than doubtful in the case of a star of Cepheus (No. 7582 of the catalogue of the British Association), which, on account of its extreme redness, has been called by William Herschel the Garnet Star (1782).

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[8] Compare Mädler, *Astr.*, s. 438, note 12, with Struve *Stellarum compos. mensuræ microm.* pp. 97 and 98, star 2140. "I believe," says Argelander, "it is extremely difficult with a telescope having a great power of illumination to estimate rightly the brightness of two such different stars as the two components of α Herculis. My experience is strongly against the variability of the companion; for during my many observations in the day-time with the telescopes of the

It would be difficult to indicate the number of periodically variable stars for the reason that the periods already determined are all irregular and uncertain, even if there were no other reasons. The two variable stars of Pegasus, as well as α Hydræ, ε Aurigæ, and α Cassiopeiæ, have not the certainty that belongs to Mira Ceti, Algol, and δ Cephei. In inserting them, therefore, in a table, much will depend on the degree of certainty we are disposed to be content with. Argelander, as will be seen from the table at the close of this investigation, reckons the number of satisfactorily determined periods at only twenty-four.[9]

The phenomenon of variability is found not only both in red, and in some white stars, but also in stars of the most diversified magnitude; as, for example, in a star of the 1st magnitude, α Orionis; by Mira Ceti, α Hydræ, α Cassiopeiæ, and β Pegasi, of the 2nd magnitude; β Persei, of the 2·3rd magnitude; and in η Aquilæ, and Lyræ, of the 3·4th magnitude. There are also variable stars, and indeed in far greater numbers, of the 6th to the 9th magnitude; such as

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meridian circles of Abo, Helsingfors, and Bonn, I have never seen α Herculis single, which would assuredly have been the case if the companion at its minimum were of the seventh magnitude. I believe the latter to be constant, and of the 5th or 5·6th magnitude.

[9] Mädler's Table (*Astron.*, s. 435) contains eighteen stars, with widely differing numerical elements. Sir John Herschel enumerates more than forty-five, including those mentioned in the notes. *Outlines*, § 819–826.

the variabiles Coronæ, Virginis, Cancri, et Aquarii. The star χ Cygni likewise presents very great fluctuations at its maximum.

That the periods of the variable stars are very irregular has been long known; but that this variability, with all its apparent irregularity, is subject to certain definite laws, was first established by Argelander. This he hopes to be able to demonstrate in a longer and independent treatise of his own. In the case of χ Cygni he considers that two perturbations in the period—the one of 100, the other of 8½—are more probable than a single period of 108. Whether such disturbances arise from changes in the process of light which is going on in the atmosphere of the star itself, or from the periodic times of some planet which revolves round the fixed star or sun χ Cygni, and by attraction influences the form of its photosphere, is still a doubtful question. The greatest irregularity in change of intensity has unquestionably been exhibited by the variabilis Scuti (Sobieski's shield). For this star diminishes, from the 5·4th, down to the 9th magnitude; and moreover, according to Pigott, it once totally disappeared at the end of the last century. At other times the fluctuations in its brightness have been only from the 6·5th to the 6th magnitude. The maximum of the variations of χ Cygni have been between the 6·7th and 4th magnitude; of Mira, from the 4th to the 2·1st magnitude. On the other hand, in the duration of its periods δ Cephei shows an *extraordinary*, and indeed of all variable stars the *greatest* regularity, as is proved by the 87 minima observed between the 10th of October, 1840, and 8th of January, 1848, and even later. In the case of ε Aurigæ, the variation of its brilliancy discovered by that indefatigable observer, Heis, of Aix-la-Chapelle,[10] extends only from the 3·4th to the 4·5th magnitude.

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[10] Argelander, in Schumacher's *Astron. Nachr.*, bd. xxvi. (1848), no. 624, s. 369.

A great difference in the maximum of brightness is exhibited by Mira Ceti. In the year 1779, for instance (on the 6th of November), Mira was only a little dimmer than Aldebaran, and indeed not unfrequently brighter than stars of the 2nd magnitude; whereas at other times this variable star scarcely attained to the intensity of the light of δ Ceti, which is of the 4th magnitude. Its mean brightness is equal to that of γ Ceti (3rd magnitude). If we designate by 0 the brightness of the faintest star visible to the naked eye, and that of Aldebaran by 50, then Mira has varied in its maximum from 20 to 47. Its probable brightness may be expressed by 30: it is oftener below than above this limit. The measure of its excess, however, when it does occur, is in proportion more considerable. No certain period of these oscillations has as yet been discovered. There are however indications of a period of 40 years, and another of 160.

The periods of variation in different stars vary as 1:250. The shortest period is unquestionably that exhibited by β Persei, being 68 hours and 49 minutes; so long at least as that of the polar star is not established at less than two days. Next to β Persei come δ Cephei (5d. 8h. 49m.), η Aquilæ (7d. 4h. 14m.), and ζ Geminorum (10d. 3h. 35m.). The longest periods are those of 30 Hydræ Hevelii, 495 days; χ Cygni, 406 days; Variabilis Aquarii, 388 days; Serpentis S, 367 days; and Mira Ceti, 332 days. In several of the variable stars it is well established that they increase in brilliancy more rapidly than they diminish. This phenomenon is the most remarkable in δ Cephei. Others, as for instance β Lyræ, have an equal period of augmentation and diminution of light. Occasionally, indeed, a difference is observed in this respect in the same stars, though at different epochs in their process of light. Generally Mira Ceti (as also δ Cephei) is more rapid in its augmentation than in its diminution; but in the former the contrary has also been observed.

*Periods within periods* have been distinctly observed in the case of Algol, of Mira Ceti, of β Lyræ, and with great probability also in χ Cygni. The decrease of the period of Algol is now unquestioned. Goodricke was unable to perceive it, but Argelander has since done so; in the year 1842 he was enabled to compare more than 100 trustworthy observations (comprising 7600 periods), of which the extremes differed from each other more than 58 years. (Schumacher's *Astron. Nachr.*, nos. 472 and 624.) The decrease in the period is becoming more and more observable.[11] For the periods of the maximum of Mira (including the maximum of brightness observed by Fabricius in 1596), a formula[12]

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[11] "If," says Argelander, "I take for the 0 epoch the minimum brightness of Algol, in 1800, on the 1st of January, at $18^h\ 1^m$ mean Paris time, I obtain the duration of the periods for :—

| | | |
|---|---|---|
| −1987 .. | $2^d\ 20^h\ 48^m$, or | $59^s{\cdot}416 \pm 0^s{\cdot}316$ |
| −1406 .. | „ | $58^s{\cdot}737 \pm 0^s{\cdot}094$ |
| − 825 .. | „ | $58^s{\cdot}393 \pm 0^s{\cdot}175$ |
| + 751 .. | „ | $58^s{\cdot}154 \pm 0^s{\cdot}039$ |
| +2328 .. | „ | $58^s{\cdot}193 \pm 0^s{\cdot}096$ |
| +3885 .. | „ | $57^s{\cdot}971 \pm 0^s{\cdot}045$ |
| +5441 .. | „ | $55^s{\cdot}182 \pm 0^s.348$ |

"In this table the numbers have the following signification:—if we designate the minimum epoch of the 1st of Jan. 1800, by 0, that immediately preceding by − 1, and that immediately following by + 1, and so on, then the duration between − 1987 and − 1986 would be exactly $2^d\ 20^h\ 48^m\ 59^s{\cdot}416$, but the duration between + 5441 and + 5442 would be $2^d\ 20^h\ 48^m\ 55^s{\cdot}182$; the former applies to the year 1784, the latter to the year 1842.

"The numbers which follow the signs ± are the probable errors. That the diminution becomes more and more rapid, is shown as well by the last number as by all my observations since 1847."

[12] Argelander's formula for representing all observations of the maxima of Mira Ceti is, as communicated by himself, as follows :—

has been established by Argelander, from which all the maxima can be so deduced that the *probable error* in a long period of variability, extending to 331 d. 8 h. does not in the mean exceed 7 days, while, on the hypothesis of an uniform period, it would be 15 days.

The double maximum and minimum of β Lyræ, in each of its periods of nearly 13 days, was from the first correctly ascertained by its discoverer, Goodricke (1784); but it has been placed still more beyond doubt[13] by very recent observations. It is remarkable that this star attains to the same brightness in both its maxima; but in its principal minimum it is about half a magnitude fainter than in the other. Since the discovery of the variability of β Lyræ, *the period in a period* has probably been on the increase. At first the variability was more rapid, then it became gradually slower; and this decrease in the length of time reached its limit between

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$$1751 \text{ Sep. } 9{\cdot}76 + 331^{d}{\cdot}3363 \text{ E.}$$
$$+10^{d}{\cdot}5, \text{ sin. } (\tfrac{360}{11}{}^{\circ} \text{ E} + 86^{\circ}\ 23') + 18^{d}{\cdot}2, \text{ sin. } (\tfrac{45}{11}{}^{\circ} \text{ E} + 231^{\circ}\ 42')$$
$$+33^{d}{\cdot}9, \text{ sin. } (\tfrac{45}{22}{}^{\circ} \text{ E} + 170^{\circ}\ 19') + 65^{d}{\cdot}3, \text{ sin. } (\tfrac{15}{11}{}^{\circ} \text{ E} + 6^{\circ}\ 37')$$

where E represents the number of maxima which have occurred since Sept. 9, 1751, and the co-efficients are given in days. Therefore, for the current year (E being = 109), the following is the maximum:—

$$1751 \text{ Sep. } 9{\cdot}76 + 36115^{d}{\cdot}65 + 8^{d}{\cdot}44 - 12^{d}{\cdot}24.$$
$$+ 18^{d}{\cdot}59 + 27^{d}{\cdot}34 = 1850 \text{ Sep. } 8^{d}{\cdot}54.$$

"The strongest evidence in favour of this formula is, that it represents even the maximum of 1596, (*Cosmos*, vol. ii. p. 713,) which, on the supposition of a uniform period, would deviate more than 100 days. However, the laws of the variation of the light of this star appear so complicated, that in *particular cases*—*e. g.* for the accurately observed maximum of 1840—the formula was wrong by many days (nearly twenty-five)."

[13] Compare Argelander's essay written on the occasion of the centenary jubilee of the Königsberg University, and entitled, *De Stella β Lyræ Variabili*, 1844.

the years 1840 and 1844. During that time its period was nearly invariable; at present it is again decidedly on the decrease. Something similar to the double maximum of β Lyræ occurs in δ Cephei. There is a tendency to a second maximum, in so far as its diminution of light does not proceed uniformly; but after having been for some time tolerably rapid, it comes to a stand, or at least exhibits a very inconsiderable diminution which suddenly becomes rapid again. In some stars it would almost appear as though the light were prevented from fully attaining a second maximum. In χ Cygni it is very probable that two periods of variability prevail,—a longer one of 100 years, and a shorter one of 8½.

The question whether, on the whole, there is greater regularity in variable stars of very short than in those of very long periods, is difficult to answer. The variations from an uniform period can only be taken relatively; *i. e.* in parts of the period itself. To commence with long periods, χ Cygni, Mira Ceti, and 30 Hydræ, must first of all be considered. In χ Cygni, on the supposition of a uniform variability, the deviations from a period of 406·0634 days, (which is the most probable period,) amount to 39·4 days. Even though a portion of these deviations may be owing to errors of observation, still at least 29 or 30 days remain beyond doubt; *i. e.* one-fourteenth of the whole period. In the case of Mira Ceti,[14] in a period of 331·340 days, the deviations amount to 55·5 days, even if we do not reckon the observations of David Fabricius. If, allowing for errors of observation, we limit the estimate to 40 days, we still obtain one-eighth; consequently, as compared with χ Cygni, nearly twice as great a deviation. In the case of 30 Hydræ, which has a period of 495 days, it is still greater, probably one-fifth. It is only during the last few years (since 1840, and still later) that the variable stars with very short periods have been observed steadily, and with sufficient accuracy; so that the problem in question, when applied to them, is still more difficult of solution. From the observations, however, which have as yet been taken, less considerable deviations seem to occur. In the case of η Aquilæ (with a period of 7d. 4h.) they only amount to one-sixteenth or one-seventeenth of the whole period; in that of β Lyræ (period 12d. 21h.) to one twenty-seventh or one-thirtieth; but the inquiry is still exposed to much uncertainty as regards the comparison of long and short periods. Of β Lyræ between 1700 and 1800 periods have been observed; of Mira Ceti, 279; of χ Cygni, only 145.

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[14] The work of Jacques Cassini (*Elémens d'Astronomie*, 1740, pp. 66–69), belongs to the earliest systematic attempts to investigate the mean duration of the period of the variation of Mira Ceti.

The question that has been mooted, whether stars which have long appeared to be variable in regular periods, ever cease to be so, must apparently be answered in the negative. As among the constantly variable stars there are some which at one time exhibit a very great, and at another a very small degree of variability, (as, for instance, variabilis Scuti,) so, it seems, there are also others whose variability is at certain times so very slight, that, with our limited means, we are unable to detect it. To such belongs variabilis Coronæ bor. (No. 5236 in the Catalogue of the British Association), recognized as variable by Pigott, who observed it for a considerable time. In the winter of 1795-6 this star became totally invisible; subsequently it again appeared, and the variations of its light were observed by Koch. In 1817, Harding and Westphal found that its brightness was nearly constant, while in 1824 Olbers was again enabled to perceive a variation in its luminosity. Its constancy now again returned, and from August, 1843, to September, 1845, was established by Argelander. At the end of September, a fresh diminution of its light commenced. By October, the star was no longer visible in the comet-seeker, but it appeared again in February, 1846, and by the beginning of June had reached its usual magnitude (the 6th). Since then it has maintained this magnitude, if we overlook some small fluctuations whose very existence has not been established with certainty. To this enigmatical class of stars belong also variabilis Aquarii, and probably Janson and Kepler's star in Cygnus of 1600, which we have already mentioned among the new stars.

TABLE of the Variable Stars by F. Argelander.

| No. | Name of the Star. | Length of Period. | Brightness in the | | Name of Discoverer and date of Discovery. | |
|---|---|---|---|---|---|---|
| | | | Maximum. | Minimum. | | |
| | | D. H. M. | Magnitude | Magnit. | | |
| 1 | *o* Ceti | 331 20 — | 4 to 2·1 | 0 | Holwarda | 1639 |
| 2 | β Persei | 2 20 49 | 2·3 | 4 | Montanari | 1669 |
| 3 | χ Cygni | 406 1 30 | 6·7 to 4 | 0 | Gottfr. Kirch | 1687 |
| 4 | 30 Hydræ Hev. | 495 — — | 5 to 4 | 0 | Maraldi | 1704 |
| 5 | Leonis R, 420 M. | 312 18 — | 5 | 0 | Koch | 1782 |
| 6 | η Aquilae | 7 4 14 | 3·4 | 5·4 | E. Pigott | 1784 |
| 7 | β Lyræ | 12 21 45 | 3·4 | 4·5 | Goodricke | 1784 |
| 8 | δ Cephei | 5 8 49 | 4·3 | 5·4 | Ditto | 1784 |
| 9 | α Herculis | 66 8 — | 3 | 3·4 | Wm. Herschel | 1795 |
| 10 | Coronæ R | 323 — — | 6 | 0 | E. Pigott | 1795 |
| 11 | Scuti R | 71 17 — | 6·5 to 5·4 | 9 to 6 | Ditto | 1795 |
| 12 | Virginis R | 145 21 — | 7 to 6·7 | 0 | Harding | 1809 |
| 13 | Aquarii R | 388 13 — | 9 to 6·7 | 0 | Ditto | 1810 |
| 14 | Serpentis R | 359 — — | 6·7 | 0 | Ditto | 1826 |
| 15 | Serpentis S | 367 5 — | 8 to 7·8 | 0 | Ditto | 1828 |
| 16 | Cancri R | 380 — — | 7 | 0 | Schwerd | 1829 |
| 17 | α Cassiopeiæ | 79 3 — | 2 | 3·2 | Birt | 1831 |
| 18 | α Orionis | 196 — — | 1 | 1·2 | John Herschel | 1836 |
| 19 | α Hydræ | 55 — — | 2 | 2·3 | Ditto | 1837 |
| 20 | ε Aurigæ | ? | 3·4 | 4·5 | Heis | 1846 |
| 21 | ζ Geminorum | 10 3 35 | 4·3 | 5·4 | Schmidt | 1847 |
| 22 | β Pegasi | 40 23 — | 2 | 2·3 | Ditto | 1848 |
| 23 | Pegasi R | 350 — — | 8 | 0 | Hind | 1848 |
| 24 | Cancri S | ? | 7·8 | 0 | Ditto | 1848 |

## EXPLANATORY REMARKS.

The 0 in the column of the minima indicates that the star is then fainter than the 10th magnitude. For the purpose of clearly and conveniently designating the smaller variable stars, which for the most part have neither names nor other designations, I have allowed myself to append to them capitals, since the letters of the Greek and the smaller Latin alphabet have, for the most part, been already employed by Bayer.

Besides the stars adduced in the preceding table, there are almost as many more which are supposed to be variable, since their magnitudes are set down differently by different observers. But as these estimates were merely occasional, and have not been conducted with much precision, and as different astronomers have different principles in estimating magnitudes, it seems the safer course not to notice any such cases, until the same observer shall have found a decided variation in them at different times. With all those adduced in the table this is the case; and the fact of their periodical change of light is quite established, even where the period itself has not been ascertained. The periods given in the table are founded, for the most part, on my own examination of all the earlier observations that have been published, and on my own observations within the last ten years, which have not as yet been published. Exceptions will be mentioned in the following notices of the several stars.

In these notices the positions are those for 1850, and are expressed in right ascension and declination. The frequently repeated term *gradation* indicates a difference of brightness, which may be distinctly recognized even by the naked eye, or in the case of those stars which are invisible to the unaided sight, by a Frauenhofer's comet-seeker of twenty-five and a-half inches focal length. For the brighter stars above the 6th magnitude, a gradation indicates about the tenth part of the difference by which the successive orders of magnitude differ from one another; for the smaller stars the usual classifications of magnitude are considerably closer.

(1) *o* Ceti, R. A. 32° 57′, Decl. —3° 40′; also called Mira, on account of the wonderful change of light which was first observed in this star. As early as the latter half of the seventeenth century, the periodicity of this star was recognized, and Bouillaud fixed the duration of its period at 333

days; it was found, however, at the same time, that this duration was sometimes longer, and sometimes shorter, and that the star at its greatest brilliancy appeared sometimes brighter, and sometimes fainter. This has been subsequently fully confirmed. Whether the star ever becomes perfectly invisible is as yet undecided; at one time, at the epoch of its minimum it has been observed of the 11th or 12th magnitude, at another, it could not be seen even with the aid of a three or a four-feet telescope. This much is certain, that for a long period it is fainter than stars of the 10th magnitude. But few observations of the star at this stage have as yet been taken; most having commenced when it had begun to be visible to the naked eye as a star of the 6th magnitude. From this period the star increases in brightness at first with great rapidity, afterwards more slowly, and at last, with a scarcely perceptible augmentation; then again, it diminishes at first slowly, afterwards rapidly. On a mean the period of augmentation of light from the 6th magnitude extends to 50 days; that of its decrease down to the same degree of brightness takes 69 days; so that the star is visible to the naked eye for about four months. However, this is only the mean duration of its visibility; occasionally it has lasted as long as five months, whereas, at other times it has not been visible for more than three. In the same way, also, the duration both of the augmentation and of the diminution of its light is subject to great fluctuations, and the former is at all times slower than the latter: as, for instance, in the year 1840, when the star took sixty-two days to arrive at its greatest brightness, and then in forty-nine days became invisible to the naked eye. The shortest period of increase that has as yet been observed took place in 1679, and lasted only thirty days; the longest (of sixty-seven days) occurred in 1709. The decrease of light lasted the longest in 1839, being then ninety-one days; the shortest in the year 1660, when it was completed in nearly fifty-two days. Occasionally, the star at the period of its greatest brightness exhibits for a whole month together scarcely any perceptible variation; at others, a difference may be observed within a very few days. On some occasions after the star had decreased in brightness for several weeks there was a period of perfect cessation; or, at least, a scarcely perceptible diminution of light during several days: this was the case in 1678 and in 1847.

The maximum brightness, as already remarked, is by no means always the same. If we indicate the brightness of the faintest star that is visible to the naked eye by 0, and that of Aldebaran, (α Tauri,) a star of the 1st magnitude, by 50, then the maximum of light of Mira fluctuates between 20 and 47, *i. e.* between the brightness of a star of the 4th, and of the 1st or 2nd magnitude: the mean brightness is 28, or that of the star γ Ceti. But the duration of its periods is still more irregular: its mean is 331d. 20h., while its fluctuations have extended to a month; for the shortest time that ever elapsed from one maximum to the next was only 306 days, the longest on the other hand 367 days. These irregularities become the more remarkable, when we compare the several occurrences of greatest brightness with those which would take place if we were to calculate these maxima on the hypothesis of an uniform period. The difference between calculation and observation then amounts to 50 days, and it appears, that for several years in succession those differences are nearly the same, and in the same direction. This evidently indicates that the disturbance in the phenomena of light is one of a very long period. More accurate calculations, however, have proved that the supposition of one disturbance is not sufficient, and that several must be assumed, which may, however, all arise from the same cause; one of these recurs after 11 single periods; a second, after 88; a third, after 176; and a fourth, after 264. From hence arises the formula of sines (given at p. 228, note 12), with which, indeed, the several maxima very nearly accord, although deviations still exist which cannot be explained by errors of observation.

(2) β Persei, Algol; R. A. 44° 36′, Decl. + 40° 22′. Although Geminiano Montanari observed the variability of this star in 1667, and Maraldi likewise noticed it, it was Goodricke that first, in 1782, discovered the regularity of the variability. The cause of this is probably that this star does not, like most other variable ones, gradually increase and diminish in brightness, but for 2d. 13h. shines uniformly as a star of the 2·3rd magnitude, and only appears less bright for 7 or 8 hours, when it sinks to the 4th magnitude. The augmentation and diminution of its brightness are not quite regular; but when near to the minimum, they proceed with greater rapidity; whence the time of least brightness may

be accurately calculated to within 10 to 15 minutes. It is moreover remarkable that this star, after having increased in light for about an hour, remains for nearly the same period at the same brightness, and then begins once more perceptibly to increase. Till very recently the duration of the period was held to be perfectly uniform, and Wurm was able to present all observations pretty closely, by assuming it to be 2d. 21h. 48m. 58½s. However, a more accurate calculation, in which was comprehended a space of time nearly twice as long as that at Wurm's command, has shown that the period becomes gradually shorter. In the year 1784, it was 2d. 20h. 48m. 59·4s., and in the year 1842, only 2d. 20h. 48m. 55·2s. Moreover, from the most recent observations it becomes very probable that this diminution of the period is at present proceeding more rapidly than before, so that foı this star also a formula of sines, for the disturbance of its period, will in time be obtained. Besides, this diminution will be accounted for, if we assume that Algol comes nearer to us by about 2000 miles every year, or recedes from us thus far less each succeeding year; for in that case his light would reach us as much sooner every year, as the decrease of the period requires; *i. e.* about the twelve thousandth of a second. If this be the true cause, a formula of sines must eventually be deduced.

(3) χ Cygni, R. A. 296° 12′, Decl. +32° 32′. This star also exhibits nearly the same irregularities as Mira. The deviations of the observed maxima from those calculated for a uniform period amount to 40 days, but are considerably diminished by the introduction of a disturbance of 8½ single periods, and of another of 100 such periods. In its maximum this star reaches the mean brightness of a faint 5th magnitude, or one gradation brighter than the star 17 Cygni. The fluctuations, however, are in this case also very considerable, and have been observed from 13 gradations below the mean to 10 above it. At this lowest maximum the star would be perfectly invisible to the naked eye, whereas, on the contrary, in the year 1847, it could be seen without the aid of a telescope for fully 97 days; its mean visibility extends to 52 days, of which, on the mean, it is 20 days on the increase, and 32 on the decrease.

(4) 30 Hydræ Hevelii, R. A. 200° 23′, Decl. — 22° 30′. Of this star, which, from its position in the heavens, is only

visible for a short time during every year, all that can be said is, that both its period and its maximum brightness are subject to very great irregularities.

(5) Leonis R, = 420 Mayeri; R. A. 144° 52′, Decl. + 12° 7′. This star is often confounded with 18 and 19 Leonis, which are close to it; and in consequence has been very little observed; sufficiently, however, to show that the period is somewhat irregular. Its brightness at the maximum seems also to fluctuate through some gradations.

(6) η Aquilæ, called also η Antinoi; R. A. 296° 12′, Decl. + 0° 37′. The period of this star is tolerably uniform, 7d. 4h. 13m. 53s.; observations, however, prove that at long intervals of time trifling fluctuations occur in it, not amounting to more than 20 seconds. The variation of light proceeds so regularly, that up to the present time no deviations have been discovered which could not be accounted for by errors of observation. In its minimum, this star is one gradation fainter than ι Aquilæ; at first it increases slowly, then more rapidly, and afterwards again more slowly; and in 2d. 9h. from its minimum, attains to its greatest brightness, in which it is nearly three gradations brighter than β, but two fainter than δ Aquilæ. From the maximum its brightness does not diminish quite so regularly; for when the star has reached the brightness of β (*i. e.* in 1d. 10h. after the maximum), it changes more slowly than either before or afterwards.

(7) β Lyræ, R. A. 281° 8′, Decl. + 33° 11′; a star remarkable from the fact of its having two maxima and two minima. When it has been at its faintest light, one-third of a gradation fainter than ζ Lyræ, it rises in 3d. 5h. to its first maximum, in which it remains three-fourths of a gradation fainter than γ Lyræ. It then sinks in 3d. 3h. to its second minimum, in which its light is about five gradations greater than that of ζ. After 3d. 2h. more, it again reaches, in its second maximum, to the brightness of the first; and afterwards, in 3d. 12h., declines once more to its greatest faintness; so that, in 12d. 21h. 46m. 40s. it runs through all its variations of light. This duration of the period, however, only applies to the years 1840 to 1844; previously it had been shorter—in the year 1784, by about 2½h.; in 1817 and 1818, by more than an hour; and, at present, a shortening of it is again clearly perceptible. There is therefore no doubt that in the

case of this star the disturbance of its period may be expressed by a formula of sines.

(8) δ Cephei, R. A. 335° 54′, Decl. + 57° 39′. Of all the known variable stars, this exhibits in every respect the greatest regularity. The period of 5d. 8h. 47m. 39½s. is given by all the observations from 1784 to the present day, allowing for errors of observation, which will account for all the slight differences exhibited in the course of the alternations of light. This star is in its minimum three-quarters of a gradation brighter than ε; in its maximum, it resembles ι of the same constellation (Cepheus). It takes 1d. 15h. to pass from the former to the latter; but, on the other hand, more than double that time, viz. 3d. 18h. to change again to its minimum: during eight hours of the latter period, however, it scarcely changes at all, and very inconsiderably for a whole day.

(9) α Herculis, R. A. 256° 57′, Decl. + 14° 34′; an extremely red double star, the variation of whose light is in every respect very irregular. Frequently, its light scarcely changes for months together; at other times, in the maximum, it is nearly five gradations brighter than in the minimum; consequently, the period also is still very uncertain. The discoverer of the star's variation had assumed it to be sixty-three days. I at first set it down at ninety-five, until a careful reduction of all my observations made during seven years at length gave me the period assigned in the text. Heis believes that he can represent all the observations by assuming a period of 184·9 days, with two maxima and two minima.

(10) Coronæ R, R. A. 235° 36′, Decl. + 28° 37′. This star is variable only at times: the period set down has been calculated by Koch from his own observations, which unfortunately have been lost.

(11) Scuti R, R. A. 279° 52′, Decl. — 5° 51′. The variations of brightness of this star are at times confined within a very few gradations, whereas at others it diminishes from the 5th to the 9th magnitude. It has been too little observed to determine when any fixed rule prevails in these deviations. The duration of the period is also subject to considerable fluctuations.

(12) Virginis R, R. A. 187° 43′, Decl. + 7° 49′. It maintains its period and its maximum brightness with tolerable regularity; some deviations, however, do occur, which appear

to me too considerable to be ascribed merely to errors of observation.

(13) Aquarii R, R. A. 354° 11′, Decl. — 16° 6′.

(14) Serpentis R, R. A. 235° 57′, Decl. + 15° 36′.

(15) Serpentis S, R. A. 228° 40′, Decl. + 14° 52′.

(16) Cancri R, R. A. 122° 6′, Decl. + 12° 9′.

Of these four stars, which have been but very slightly observed, little more can be said than what is given in the table.

(17) *α* Cassiopeiæ, R. A. 8° 0′, Decl. + 55° 43′. This star is very difficult to observe. The difference between its maximum and minimum only amounts to a few gradations, and is, moreover, as variable as the duration of the period. This circumstance explains the varying statements on this head. That which I have given, which satisfactorily represents the observations from 1782 to 1849, appears to me the most probable one.

(18) *α* Orionis, R. A. 86° 46′, Decl. + 7° 22′. The variation in the light of this star likewise amounts to only four gradations from the minimum to the maximum. For 91½ days it increases in brightness, while its diminution extends over 104½, and is imperceptible from the twentieth to the seventieth day after the maximum. Occasionally its variability is scarcely noticeable. It is a very red star.

(19) *α* Hydræ, R. A. 140° 3′, Decl. — 8° 1′. Of all the variable stars, this is the most difficult to observe, and its period is still altogether uncertain. Sir John Herschel sets it down at from twenty-nine to thirty days.

(20) *ε* Aurigæ, R. A. 72° 48′, Decl. + 43° 36′. The alternation of light in this star is either extremely irregular, or else, in a period of several years, there are several maxima and minima—a question which cannot be decided for many years.

(21) *ζ* Geminorum, R. A. 103° 48′, Decl. + 20° 47′. This star has hitherto exhibited a perfectly regular course in the variations of its light. Its brightness at its minimum keeps the mean between *ν* and *υ* of the same constellation; in the maximum it does not quite reach that of *λ*. It takes 4d. 21h. to attain its full brightness, and 5d. 6h. for its diminution.

(22) *β* Pegasi, R. A. 344° 7′, Decl. + 27° 16′. Its period is pretty well ascertained, but as to the course of its variation of light nothing can as yet be asserted.

(23) Pegasi R, R. A. 344° 47′, Decl. + 9° 43′.

(24) Cancri S, R. A. 128° 50′, Decl. + 19° 34′.
Of these two stars, nothing at present can be said.

*Bonn, August*, 1850. FR. ARGELANDER.

VARIATION OF LIGHT IN STARS WHOSE PERIODICITY IS UNASCERTAINED.—In the scientific investigation of important natural phenomena, either in the terrestrial or in the sidereal sphere of the Cosmos, it is imprudent to connect together, without due consideration, subjects which, as regards their proximate causes, are still involved in obscurity. On this account we are careful to distinguish stars which have appeared and again totally disappeared (as in the star in Cassiopeia, 1572);—stars which have newly appeared and not again disappeared (as that in Cygnus, 1600);—variable stars with ascertained periods (Mira Ceti, Algol); and stars whose intensity of light varies, of whose variation, however, the periodicity is as yet unascertained (as η Argûs). It is by no means improbable, but still does not necessarily follow that these four kinds of phenomena[15] have perfectly similar causes in the photospheres of those remote suns, or in the nature of their surfaces.

As we commenced our account of new stars with the most remarkable of this class of celestial phenomena—the sudden appearance of Tycho Brahe's star—so, influenced by similar considerations, we shall begin our statements concerning the variable stars whose periods have not yet been ascertained, with the unperiodical fluctuations in the light of η Argûs, which to the present day are still observable. This star is situated in the great and magnificent constellation of the Ship, "the glory of the southern skies." Halley, as long ago as 1677, on his return from his voyage to St. Helena, expressed strong doubts concerning the alternation of light in the stars of Argo, especially on the shield of the prow and on the deck (ἀσπιδίσκη and κατάστρωμα), whose relative orders of magnitude had been given by Ptolemy.[16] However, in consequence of the little reliance that can be placed on the positions of the stars as set down by the ancients, of the various readings in the several MSS. of the Almagest, and of the vague estimates of intensity of light, these doubts failed to lead to any result. According to Halley's observation in 1677, η Argûs was of the 4th magnitude; and by 1751, it was already of the 2nd, as observed by Lacaille. The star must have afterwards returned to its fainter light, for Burchell, during his residence in Southern Africa, from 1811 to 1815, found it of the 4th magnitude; from 1822 to 1826, it was of the 2nd, as seen by Fallows and Brisbane; in February, 1827, Burchell, who happened at that time to be at San Paolo, in Brazil, found it of the 1st magnitude, perfectly equal to α Crucis. After a year, the star returned to the 2nd magnitude. It was of this magnitude when Burchell saw it on the 29th of February, 1828, in the Brazilian town of Goyaz; and it is thus set down by Johnson and Taylor, in their catalogues for the period between 1829 and 1833. Sir John Herschel also, at the Cape of Good Hope, estimated it as being between the 2nd and 1st magnitude, from 1834 to 1837.

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[15] Newton (*Philos. Nat. Principia mathem.*, ed. Le Seur et Jacquier, 1760, tom. iii. p. 671) distinguishes only two kinds of these sidereal phenomena. "Stellæ fixæ quæ per vices apparent et evanescunt, quæque paulatim crescunt, videntur revolvendo partem lucidam et partem obscuram per vices ostendere." The fixed stars which alternately appear and vanish and which gradually increase, appear by turns to show an illuminated and a dark side. This explanation of the variation of light had been still earlier advanced by Riccioli. With respect to the caution necessary in predicating periodicity, see the valuable remarks of Sir John Herschel, in his *Observations at the Cape*, § 261.

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[16] Delambre, *Hist. de l'Astron. ancienne*, tom. ii. p. 280, and *Hist. de l'Astron. au* 18*ième Siècle*, p. 119.

When, on the 16th of December, 1837, this famous astronomer was preparing to take the photometric measurements of the innumerable telescopic stars, between the 11th and 16th magnitudes, which compose the splendid nebula around $\eta$ Argûs, he was astonished to find this star, which had so often before been observed, increase to such intensity of light that it almost equalled the brightness of $\alpha$ Centauri, and exceeded that of all other stars of the 1st magnitude, except Canopus and Sirius. By the 2nd of January, 1838, it had for that time reached the maximum of its brightness. It soon became fainter than Arcturus; but in the middle of April, 1838, it still surpassed Aldebaran. Up to March, 1843, it continued to diminish, but was even then a star of the 1st magnitude; after that time, and especially in April, 1843, it began to increase so much in light, that, according to the observations of Mackay at Calcutta, and Maclear at the Cape, $\eta$ Argûs became more brilliant than Canopus, and almost equal to Sirius.[17] This intensity of light was continued almost up to the beginning of the present year (1850). A distinguished observer, Lieutenant Gilliss, who commands the Astronomical Expedition sent by the Government of the United States to the Coast of Chili, writes from Santiago, in February, 1850: "$\eta$ Argûs, with its yellowish-red light, which is darker than that of Mars, is at present next in brilliancy to Canopus, and is brighter than the united light of $\alpha$ Centauri."[18] Since the appearance of the new stars in Ophiuchus in 1604, no fixed star ha attained to such an intensity of light, and for so long a period—now nearly seven years. In the 173 years (from 1677 to 1850) during which we have reports of the magnitude of this beautiful star in Argo, it has undergone from eight to nine oscillations in the augmentation and diminution of its light. As an incitement to astronomers to continue their observations on the phenomenon of a great but unperiodical variability in $\eta$ Argûs, it was fortunate that its appearance was coincident with the famous five years' expedition of Sir John Herschel to the Cape.

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[17] Compare Sir John Herschel's *Observations at the Cape*, § 71–78; and *Outlines of Astron.*, § 830 (*Cosmos*, vol. i. p. 144).

[18] Letter of Lieutenant Gilliss, astronomer of the Observatory at Washington, to Dr. Flügel, Consul of the United States of North America at Leipsic (in manuscript). The

In the case of several other stars, both isolated and double, observed by Struve (*Stellarum compos. Mensuræ Microm.*, pp. lxxi.-lxxiii.) similar variations of light have been noticed, which have not as yet been ascertained to be periodical. The instances which we shall content ourselves with adducing, are founded on actual photometrical *estimations* and *calculations* made by the same astronomer at different times, and not on the alphabetical series of Bayer's Uranometry. In his treatise *De fide Uranometriæ Bayerianæ*, 1842, (p. 15,) Argelander has satisfactorily shown that Bayer did not by any means follow the plan of designating the brightest stars by the first letters of the alphabet; but that, on the contrary, he arranged the letters by which he designated stars of equal magnitude according to the positions of the stars in a constellation, beginning usually at the head, and proceeding, in regular order, down to the feet. The order of letters in

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cloudless purity and transparency of the atmosphere, which last for eight months, at Santiago, in Chili, are so great, that Lieutenant Gilliss, (with the *first great telescope ever constructed in America*, having a diameter of 7 inches, constructed by Henry Fitz of New York, and William Young of Philadelphia), was able clearly to recognize the sixth star in the trapezium of Orion.

Bayer's *Uranometria* has long led to a belief that a change of light has taken place in α Aquilæ, in Castor Geminorum, and in Alphard of Hydra.

Struve, in 1838, and Sir John Herschel, observed Capella increase in light. The latter now finds Capella much brighter than Vega, though he had always before considered it fainter.[19] Galle and Heis come to the same conclusion, from their present comparison of Capella and Vega. The latter finds Vega between 5 and 6 gradations, consequently more than half a magnitude, the fainter of the two.

The variations in the light of some stars in the constellations of the Greater and of the Lesser Bear are deserving of especial notice. "The star η Ursæ majoris," says Sir John Herschel, "is at present certainly the most brilliant of the seven bright stars in the Great Bear, although, in 1837, ε unquestionably held the first place among them." This remark induced me to consult Heis, who so zealously and carefully occupies himself with the variability of stellar light. "The following," he writes, "is the order of magnitude which results from my observations, carried on at Aix-la-Chapelle between 1842 and 1850: 1. ε Ursæ majoris, or Alioth; 2. α, or Dubhe; 3. η, or Benetnasch; 4. δ, or Mizar; 5. β; 6. γ; 7. δ. The three stars, ε, α, and η, of this group are nearly equal in brightness, so that the slightest want of clearness in the atmosphere might render their order doubtful; ζ is decidedly fainter than the three before mentioned. The two stars β and γ, (both of which are decidedly duller than ζ) are nearly equal to each other; lastly δ, which in ancient maps is usually set down as of the same magnitude with β and γ, is by more than a magnitude fainter than these; ε is decidedly variable. Although in general this star is brighter, I have nevertheless in three years observed it on five occasions to be undoubtedly fainter than α. I also consider β Ursæ majoris to be variable, though I am unable to give any fixed periods. In the years 1840 and 1841, Sir John Herschel found β Ursæ minoris much brighter than the Polar star; whereas still earlier, in May, 1846, the contrary was observed by him. He also conjectures β to be variable.[20] Since 1843, I have, as a rule, found Polaris fainter than β Ursæ minoris; but from October, 1843, to July, 1849, Polaris was, according to my registers, 14 times brighter than β. I have had frequent opportunities of convincing myself that the colour of the last-named star is not always equally red; it is at times more or less yellow, at others most decidedly red."[21] All the pains and labour spent in determining the relative brightness of the stars will never attain any certain result until the arrangement of their magnitudes from mere estimation shall have given place to methods of measurement founded on the progress of modern optical science.[22] The possibility of attaining such an object need not be despaired of by astronomers and physicists.

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[19] Sir John Herschel (*Observations at the Cape*, pp. 334, 350, note 1, and 440). For older observations of Capella and Vega, see William Herschel, in the *Philos. Transact.*, 1797, p. 307, 1799, p. 121; and Bode's *Jahrbuch für* 1810, s. 148. Argelander, on the other hand, advances many doubts as to the variation of Capella and of the stars of the Bear.

The probably great physical similarity in the process of light in all self-luminous stars (in the central body of our own planetary system, and in the *distant suns* or fixed stars) has long and justly directed attention to the importance[23] and significance which attach to the periodical or non-periodical variation in the light of the stars in reference to climatology generally;—to the history of the atmosphere, or the varying temperature which our planet has derived in the course of thousands of years from the radiation of the sun;—with the condition of organic life, and its forms of development in different degrees of latitude. The variable star in the neck of the Whale (Mira Ceti) changes from the 2nd magnitude to the 11th, and sometimes vanishes altogether; we have seen that η Argûs has increased from the 4th to the 1st magnitude, and among the stars of this class has attained to the brilliancy of Canopus, and almost to that of Sirius. Supposing that our own sun has passed through only a very few of these variations in intensity of light and heat, either in an increasing or decreasing ratio, (and why should it differ from other suns?) such a change, such a weakening or augmentation of its light-process, may account for far greater and more fearful results for our own planet than any required for the explanation of all geognostic relations, and ancient telluric revolutions. William Herschel and Laplace were the first to agitate these views. If I have dwelt upon them somewhat at length, it is not because I would seek exclusively in these the solution of the great problem of the changes of temperature in our earth. The primitive high temperature of this planet at its formation, and the solidification of conglomerating matter—the radiation of heat from the deeper strata of the earth through open fissures, and through unfilled veins—the greater power of electric currents—a very different distribution of sea and land;—*may* also, in the earliest epochs of the earth's existence, have rendered the diffusion of heat independent of latitude; that is to say, of position relatively to a central body. Cosmical considerations must not be limited merely to astrognostic relations.

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[20] *Observations at the Cape*, § 259, note 260.

[21] Heis, in his *Manuscript Notices of May*, 1850; also *Observations at the Cape*, p. 325; and P. von Boguslawski. *Uranus for* 1848, p. 186. The asserted variation of η, α, and δ Ursæ maj. is also confirmed in *Outlines*, p. 559. See Mädler, *Astr.*, p. 432. On the succession of the stars which, from their proximity, will in time mark the north pole, until, after the lapse of 12000 years, Vega, the brightest of all possible polar stars, will take their place.

[22] *Cosmos*, vide supra, p. 128.

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[23] William Herschel, *On the Changes that happen to the Fixed Stars*, in the *Philos. Transact.* for 1796, p. 186. Sir John Herschel in the *Observations at the Cape*, pp. 350–352; as also in Mrs. Somerville's excellent work, *Connexion of the Physical Sciences*, 1846, p. 407.

## V.

### PROPER MOTION OF THE FIXED STARS.—PROBLEMATICAL EXISTENCE OF DARK COSMICAL BODIES.—PARALLAX.—MEASURED DISTANCES OF SOME OF THE FIXED STARS.—DOUBTS AS TO THE ASSUMPTION OF A CENTRAL BODY FOR THE WHOLE SIDEREAL HEAVENS.

THE heaven of the fixed stars, in contradiction to its very name, exhibits, not only changes in the intensity of light, but also further variation from the perpetual motion of the individual stars. Allusion has already been made to the fact that, without disturbing the equilibrium of the star-systems, no fixed point is to be found in the whole heavens, and that of all the bright stars observed by the earliest of the Greek astronomers, not one has kept its place unchanged. In the case of Arcturus, of $\mu$ Cassiopeiæ, and of a double star in Cygnus, this change of position has, by the accumulation of their annual proper motion during 2000 years, amounted respectively to 2½, 3½, and 6 moon's diameters. In the course of 3000 years about twenty fixed stars will have changed their places by 1° and upwards.[1] Since the proper motions of the fixed stars rise from $\frac{1}{20}$th of a second to 7·7 seconds (and consequently differ, at the least, in the ratio of 1:154), the relative distances also of the fixed stars from each other, and the configuration of the constellations themselves, cannot in long periods remain the same. The Southern Cross will not always shine in the heavens exactly in its present form; for the four stars of which it consists move with unequal velocity in different paths. How many thousand years will elapse before its total dissolution, cannot be calculated. In the relations of space and the duration of time, no absolute idea can be attached to the terms *great* and *small*.

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[1] Encke, *Betrachtungen über die Anordnung des Sternsystems*, s. 12. *Vide supra*, p. 30. Mädler, *Astr.*, s. 445.

In order to comprehend under one general point of view the changes that take place in the heavens, and all the modifications which in the course of centuries occur in the *physiognomic character* of the vault of heaven, or in the aspect of the firmament from any particular spot, we must reckon as the active causes of this change: (1), the precession of the equinoxes and the nutation of the earth's axis, by the combined operation of which new stars appear above the horizon, and others become invisible; (2), the periodical and non-periodical variations in the brightness of many of the fixed stars; (3), the sudden appearance of new stars, of which a few have continued to shine in the heavens; (4), the revolution of telescopic double stars round a common centre of gravity. Among these so-called fixed stars which change slowly and unequally both in the intensity of their light and in their position, twenty principal planets move in a more rapid course, five of them being accompanied by twenty satellites. Besides the innumerable, but undoubtedly rotatory fixed stars, forty moving planetary bodies have up to this time (October, 1850) been discovered. In the time of Copernicus and of Tycho Brahe, the great improver of the science of observation, only seven were known. Nearly two hundred comets, five of which have short periods of revolution and are interior, or, in other words, are inclosed within those of the principal planets, still remain to be mentioned in our list of planetary bodies. Next to the actual planets and the new cosmical bodies which shine forth suddenly as stars of the 1st magnitude, the comets, when, during their usually brief appearance they are visible to the naked eye, contribute the most vivid animation to the rich *picture*—I had almost said the impressive *landscape*—of the starry heavens.

The knowledge of the proper motion of the fixed stars is closely connected historically with the progress of the science of observation through the improvement of instruments and methods. The discovery of this motion was first rendered practicable when the telescope was combined with *graduated instruments;* when from the accuracy of within a minute of an arc (which after much pains Tycho Brahe first succeeded in giving to his observations on the Island of Hven) astronomers gradually advanced to the accuracy of a second and the parts of a second;—and when it became possible to compare with one another results separated by a long series of years. Such a comparison was made by Halley with respect to the positions of Sirius, Arcturus, and Aldebaran, as determined by Ptolemy in his Hipparchian catalogue, 1844 years before. By this comparison he considered himself justified (1717) in announcing the fact of a *proper* motion in the three above-named fixed stars.[3] The high and well-merited attention which, long subsequent even to the observations of Flamstead and Bradley, was paid to the table of right ascensions contained in the *Triduum* of Römer, stimulated Tobias Mayer (1756), Maskelyne (1770), and Piazzi (1800), to compare

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[3] Halley, in the *Philos. Transact.* for 1717–1719, vol. xxx. p. 736. The essay, however, referred solely to variations in latitude. Jacques Cassini was the first to add variations in longitude. (Arago, in the *Annuaire pour* 1842, p. 387.)

Römer's observations with more recent ones.[3] The proper motion of the stars was in some degree recognized as a general fact, even in the middle of the last century; but for the more precise and numerical determination of this class of phenomena we are indebted to the great work of William Herschel in 1783, founded on the observations of Flamstead,[4] and still more to Bessel and Argelander's successful comparison of Bradley's "Positions of the Stars for 1755" with recent catalogues.

The discovery of the proper motion of the fixed stars has proved of so much the greater importance to physical astronomy, as it has led to a knowledge of the motion of our own solar system through the star-filled realms of space, and, indeed, to an accurate knowledge of the direction of this motion. We should never have become acquainted with this fact, if the proper progressive motion of the fixed stars were so small as to elude all our measurements. The zealous attempts to investigate this motion, both in its quantity and its direction, to determine the parallax of the fixed stars, and their distances, have, by leading to the improvement and perfection of arc-graduation and optical instruments in connexion with micrometric appliances, contributed more than anything else to raise the science of observation to the height which, by the ingenious employment of great meridian-circles, refractors, and heliometers, it has attained, especially since the year 1830.

The quantity of the measured proper motions of the stars varies, as we intimated at the commencement of the present section, from the twentieth part of a second almost to eight seconds. The more luminous stars have in general a slower motion than stars from the 5th to the 6th and

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[3] Delambre, *Hist. de l'Astron. moderne*, t. ii. p. 658. Also in *Hist. de l'Astron. au* 18*ème siècle,* p. 448.

[4] *Philos. Transact.*, vol. lxxiii. p. 138.

7th magnitudes.[5] Seven stars have revealed an unusually great motion, namely:—Arcturus, 1st magnitude (2″·25); α Centauri, 1st magnitude (3″·58);[6] μ Cassiopeiæ, 6th magnitude (3·″ 74); the double star, δ Eridani, 5·4 magnitude (4″·08); the double star 61 Cygni, 5·6 magnitude, (5″·123), discovered by Bessel in 1812, by means of a comparison with Bradley's observations; a star in the confines of the Canes Venatici,[7] and the Great Bear, No. 1830 of the catalogue of the circumpolar stars by Groombridge, 7th magnitude (according to Argelander, 6″·974); ε Indi (7″·74, according to D'Arrest);[8] 2151 Puppis, 6th magnitude (7″·871). The arithmetical[9] mean of the several proper motions of the fixed stars in all the zones into which the sidereal sphere has been divided by Mädler, would scarcely exceed 0″·102.

An important inquiry into the "Variability of the proper motions of Procyon and Sirius," in the year 1844, a short time, therefore, before the beginning of his last and painful illness, led Bessel, the greatest astronomer of our time, to the conviction "that stars whose variable motion becomes apparent by means of the most perfect instruments, are parts of systems confined to very limited spaces in proportion to their great distances from one another." This belief in the existence of double stars, one of which is devoid of light, was so firmly fixed in Bessel's mind, as my long correspondence with him testifies, that it excited the most universal attention, partly on his account, and partly from the great interest which independently attaches itself to every enlargement of our knowledge of the physical constitution of the sidereal heavens. "The attracting body," this celebrated observer remarked, "must be very near either to the fixed star which reveals the observed change of position, or to the sun. As, however, the presence of no attracting body of considerable mass at a very small distance from the sun, has yet been perceived in the motions of our own planetary system, we are brought back to the supposition of its *very small distance from a star*, as the only tenable explanation of that change in the proper motion which, in the course of a century, becomes appreciable."[10] In a letter (dated July, 1844) in answer to one in which I had jocularly expressed my anxiety regarding the spectral world of dark stars, he writes: "At all events, I continue in the belief that Procyon and Sirius are true double stars, consisting of a visible and an invisible star. No reason exists for considering luminosity an essential property of these bodies. The fact that numberless stars are visible, is evidently no proof against the existence of an equally incalculable number of invisible ones. The physical difficulty of a change in the proper motion, is satisfactorily set aside by the hypothesis of dark stars. No blame attaches to the simple supposition that the change of velocity only takes place in consequence of the action of a force, and that forces act in obedience to the Newtonian laws."

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[5] Bessel, in the *Jahrbuch von Schumacher für* 1839, s. 38. Arago, *Annuaire pour* 1842, p. 389.

[6] α Centauri, see Henderson and Maclear, in the *Memoirs of the Astron. Soc.*, vol. xi. p. 61; and Piazzi Smyth, in the *Edinburgh Transact.*, vol. xvi. p. 447. The proper motion of Arcturus, 2″·25 (Baily, in the same *Memoirs*, vol. v. p. 165), considered as that of a very bright star, may be called very large in comparison with Aldebaran, 0″·185 (Mädler, *Centralsonne*, s. 11), and α Lyræ, 0″·400. Among the stars of the 1st magnitude, α Centauri, with its great proper motion of 3″·58, forms a very remarkable exception. The proper motion of the binary system of Cygnus amounts, according to Bessel (Schum. *Astr. Nachr.*, bd. xvi. s. 93), to 5″·123.

[7] Schumacher's *Astr. Nachr.*, no. 455.

[8] *Op. cit.*, no. 618, s. 276. D'Arest founds this result on comparisons of Lacaille (1750) with Brisbane (1825), and of Brisbane with Taylor (1835). The star 2151, Puppis, has a proper motion of 7″·871, and is of the 6th magnitude. (Maclear, in Mädler's *Unters. über die Fixstern-Systeme*, th. ii. s. 5.)

[9] Schum. *Astr. Nachr.*, no. 661, s. 201.

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[10] Schum. *Astr. Nachr.*, nos. 514–516.

A year after Bessel's death, Fuss, at Struve's suggestion, renewed the investigation of the anomalies of Procyon and Sirius, partly with new observations with Ertel's meridian-telescope at Pulkowa, and partly with reductions of, and comparisons with, earlier observations. The result, in the opinion of Struve and Fuss[11] proved adverse to Bessel's assertion. A laborious investigation which Peters has now completed at Königsberg, on the other hand, justifies it; as does also a similar one advanced by Schubert, the calculator for the North American *Nautical Almanack*.

The belief in the existence of non-luminous stars was diffused even among the ancient Greeks, and especially in the earliest ages of Christianity. It was assumed that among the fiery stars which are nourished by the celestial vapours, there revolve certain other earthlike bodies, which, however, remain invisible to us."[12] The total extinction of *new* stars, especially of those so carefully observed by Tycho Brahe and Kepler in Cassiopeia and Ophiuchus, appears to corroborate this opinion. Since it was at the time conjectured that the first of these stars had already twice appeared, and that too at intervals of nearly 300 years, the idea of *annihilation* and total extinction naturally gained little or no credit. The immortal author of the *Mécanique Céleste* bases his conviction of the existence of non-luminous masses in the Universe on these same phenomena of 1572 and 1604: "These stars that have become invisible after having surpassed the brilliancy of Jupiter, have not changed their place during the time of their being visible." (The luminous process in them has simply ceased.) "There exist therefore in celestial space dark bodies of equal magnituder, and probably in as great numbers as the stars."[13] So also Mädler, in his *Untersuchungen über die Fixstern-Systeme*, says:[14]—"A dark body might be a central body; it might, like our own sun, be surrounded in its immediate neighbourhood only by dark bodies like our planets. The motions of Sirius and Procyon, pointed out by Bessel, force us to the assumption that there are cases where luminous bodies form the satellites of dark masses."[11] It has been already remarked that the advocates of the emanation theory consider these masses as both invisible, and also as radiating light: invisible, since they are of such huge dimensions that the rays of light emitted by them (the molecules of light) being impeded by the force of attraction, are unable to pass beyond a certain limit.[15] If, as may well be assumed, there exist, in the regions of space, dark invisible bodies in which the process of light-producing vibration does not take place, these dark bodies cannot fall within the sphere of our own planetary and cometary system, or at all events their mass can only be very small, since their existence is not revealed to us by any appreciable disturbances.

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[11] Struve, *Etudes d'Astr. stellaire*, Texte, p. 47, Notes, pp. 26, and 51–57; Sir John Herschel, *Outl.*, § 859 and 860.

[12] Origen, in *Gronov. Thesaur.*, t. x. p. 271.

The inquiry into the quantity and direction of *the motion of the fixed stars*, (both of the *true* motion proper to them, and also of their *apparent* motion, produced by the change in the place of observation, as the earth moves in its orbit,) the

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[13] Laplace, *Expos. du Syst. du Monde*, 1824, p. 395. Lambert, in his *Kosmologische Briefe*, shows remarkable tendency to adopt the hypothesis of large dark bodies.

[14] Mädler, *Untersuch. über die Fixstern-Systeme*, th. ii. (1848), s. 3; and his *Astronomy*, s. 416.

[15] *Cosmos*, vol. iii. p. 117 and note: Laplace, in Zach's *Allg. Geogr. Ephem.*, bd. iv. s. 1; Mädler, *Astr.*, s. 393.

*determination* of the distances of the fixed stars from the sun, by ascertaining their *parallax;* and the conjecture as to the part *in universal space towards which our planetary system* is moving—are three problems in astronomy, which, through the means of observation already successfully employed in their partial solution, are closely connected with each other. Every improvement in the instruments and methods which have been used for the furtherance of any one of these difficult and complicated problems, has been beneficial to the others. I prefer commencing with the parallaxes and the determination of the distances of certain fixed stars, to complete that which especially relates to our present knowledge of isolated fixed stars.

As early as the beginning of the seventeenth century, Galileo had suggested the idea of measuring the "certainly very unequal distances of the fixed stars from the solar system," and indeed with great ingenuity, was the first to point out the means of discovering the parallax: not by determining the stars' distance from the zenith or the pole, "but by the careful comparison of one star with another very near it." He gives, in very general terms, an account of the micrometrical method, which William Herschel, (1781,) Struve, and Bessel subsequently made use of. "Perchè io non credo," says Galileo,[16] in his third dialogue (Giornata terza), "che tutte le stelle siano sparse in una sferica superficie *egualmente distanti da un centro*; ma stimo, che le loro lontananze da noi siano talmente varie, che alcune ve ne possano esser 2 e 3 volte più remote di alcune altre; talchè quando si trovasse col telescopio *qualche picciolissima stella vicinissima ad alcuna delle maggiori*, e che

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[16] *Opere di Galileo Galilei*, vol. xii. Milano, 1811, p. 206. This remarkable passage, which expresses the possibility and the project of a measurement, was pointed out by Arago; see his *Annuaire pour* 1842, p 382.

però quella fusse altissima, *potrebbe accadere che qualche sensibil mutazione succedesse tra di loro.*" "Wherefore I do not believe," says Galileo, in his third discourse (Giornata terza), "that all the stars are scattered over a spherical superficies, *at equal distances from a common centre;* but I am of opinion that their distances from us are so various that some of them may be two or three times as remote as others, so that when some minute star is discovered by the telescope close to one of the larger, and yet the former is highest, it may be that some sensible change might take place among them." The introduction of the Copernican system imposed, as it were, the necessity of numerically determining, by means of measurement, the change of direction occasioned in the position of the fixed stars by the earth's semi-annual change of place in its course round the sun. Tycho Brahe's angular determinations, of which Kepler so successfully availed himself, do not manifest any perceptible change arising from parallax in the apparent positions of the fixed stars, although, as I have already stated, they are accurate to a minute of the arc. For this the Copernicans long consoled themselves with the reflection, that the diameter of the earth's orbit (165⅓ millions of geographical miles) was insignificant, when compared to the immense distance of the fixed stars.

The hope of being able to determine the existence of parallax must accordingly have been regarded as dependent on the perfection of optical and measuring instruments, and on the possibility of accurately measuring very small angles. As long as such accuracy was only secure within a minute, the nonobservance of parallax merely testified to the fact, that the distance of the fixed stars must be more than 3438 times the earth's mean distance from the sun, or semi-diameter of its orbit.[17]

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[17] Bessel, in Schumacher's *Jahrb. für* 1839, s. 511.

This *lower* limit of distances rose to 206265 semi-diameters when certainty to a second was attained in the observations of the great astronomer, James Bradley; and in the brilliant period of Frauenhofer's instruments, (by the direct measurement of about the 10th part of a second of arc) it rose still higher to 2062648 mean distances of the earth. The labours and the ingeniously contrived zenith apparatus of Newton's great contemporary, Robert Hooke (1669), did not lead to the desired end. Picard, Horrebow, (who worked out Römer's rescued observations) and Flamstead, believed that they had discovered parallaxes of several seconds, whereas they had confounded the *proper* motions of the stars with the true changes from parallax. On the other hand, the ingenious John Michell (*Phil. Trans.* 1767, vol. lvii. pp. 234–264), was of opinion that the parallaxes of the nearest fixed stars must be less than 0″·02, and in that case could only "become perceptible when magnified 12000 times." In consequence of the widely diffused opinion, that the superior brilliancy of a star must invariably indicate a greater proximity, stars of the 1st magnitude, as, for instance, Vega, Aldebaran, Sirius, and Procyon, were, with little success, selected for observation by Calandrelli and the meritorious Piazzi (1805). These observations must be classed with those which Brinkley published in Dublin (1815), and which ten years afterwards were refuted by Pond, and especially by Airy. An accurate and satisfactory knowledge of parallaxes, founded on micrometric measurements, dates only from between the years 1832 and 1838.

Although Peters,[18] in his valuable work on the distances of the fixed stars (1846), estimates the number of parallaxes hitherto discovered at 33, we shall content ourselves with referring to 9, which deserve greater, although very different, degrees of confidence, and which we shall consider in the probable order of their determinations.

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[18] Struve, *Astr. stell.*, p. 104.

The first place is due to the star 61 Cygni, which Bessel has rendered so celebrated. The astronomer of Königsberg determined, in 1812, the large proper motion of this double star, (below the 6th magnitude,) but it was not until 1838, that, by means of the heliometer, he discovered its parallax. Between the months of August, 1812, and November, 1813, my friends Arago and Mathieu instituted a series of numerous observations, for the purpose of finding the parallax of the star 61 Cygni, by measuring its distance from the zenith. In the course of their labours they arrived at the very correct conclusion that the parallax of this star was less than half a second.[19] So late as 1815 and

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[19] Arago, in the *Connaissance des Temps pour* 1834, p. 281: —"Nous observâmes avec beaucoup de soin, Mr. Mathieu et moi, pendant le mois d'Août, 1812, et pendant le mois de Novembre suivant, la hauteur angulaire de l'étoile audessus de l'horizon de Paris. Cette hauteur, à la seconde époque, ne surpasse la hauteur angulaire à la première que de 0″·66. Une parallaxe absolue d'une seule seconde aurait nécessairement amené entre ces deux hauteurs une différence de 1″·2. Nos observations n'indiquent donc pas que le rayon de l'orbite terreste, que 39 millions de lieues soient vus de la 61ᵉ du Cygne sous un angle de plus d'une demi-seconde. Mais une base vue perpendiculairement soutend un angle d'une demi-seconde quand on est éloigné de 412 mille fois sa longueur. Donc la 61ᵉ du Cygne est au moins à une distance de la terre égale à 412 mille fois 39 millions de lieues." "During the month of August, 1812, and also during the following November, Mr. Mathieu and myself very carefully observed the altitude of the star above the horizon, at Paris. At the latter period its altitude only exceeded that of the former by 0″·66. An absolute parallax of only a single second would necessarily have occasioned a difference of 1″·2 between these heights. Our observations do not therefore show that a semi-diameter of the earth's orbit, or 39 millions of leagues, are seen from the star 61 of Cygnus, at an angle of more than 0″·5. But a base viewed perpendicularly sub-

1816, Bessel, to use his own words, "had arrived at no available result."[20] The observations taken from August, 1837, to October, 1838, by means of the great heliometer erected in 1829, first led him to the parallax of 0″·3483, which corresponds with a distance of 592200 mean distances of the earth, and a period of 9¼ years for the transmission of its light. Peters confirmed this result in 1842, by finding 0″·3490, but subsequently changed Bessel's result into 0″·3744 by a correction for temperature.[21]

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tends an angle of 0″·5 only when it is observed at a distance of 412000 times its length. Therefore the star 61 Cygni is situated at a distance from our earth at least equal to 412 thousand times 39 millions of leagues."

[20] Bessel, in Schum. *Jahrb.* 1839, s. 39–49, and in the *Astr. Nachr.*, no. 366, gave the result 0″·3136, as a first approximation. His later and final result was 0″·3483. (*Astr. Nachr.*, no. 402, in bd. xvii. s. 274.) Peters obtained by his own observations the following, almost identical, result, of 0″·3490. (Struve, *Astr. stell.*, p. 99.) The alteration which, after Bessel's death, was made by Peters in Bessel's calculations of the angular measurements, obtained by the Königsberg heliometer, arises from the circumstance that Bessel expressed his intention (*Astr. Nachr.*, bd. xvii. s. 267) of investigating further the influence of temperature on the results exhibited by the heliometer. This purpose he had in fact partially fulfilled in the first volume of his *Astronomische Untersuchungen*, but he had not applied the corrections of temperature to the observations of parallax. This application was made by the eminent astronomer Peters (*Ergänzungsheft zu den Astr. Nachr.*, 1849, s. 56), and the result obtained, owing to the corrections of temperature, was, 0″·3744 instead of 0″·3483.

[21] This result of 0″·3744 gives, according to Argelander, as the distance of the double star 61 Cygni from the sun, 550900 mean distances of the earth from the sun, or 45576000 millions of miles, a distance light traverses in 3177 mean days. To judge from the three consecutive statements of parallax

The parallax of the finest double star of the southern hemisphere (α Centauri) has been calculated at 0″·9128 by the observations of Henderson, at the Cape of Good Hope, in 1832, and by those of Maclear, in 1839.[22] According to this statement it is the nearest of all the fixed stars that have yet been measured, being three times nearer than 61 Cygni.

The parallax of α Lyræ has long been the object of Struve's observations. The earlier observations (1836) gave[23] between 0″·07 and 0″·18; later ones gave 0″·2613, and a distance of 771400 mean distances of the earth, with a period of twelve years for the transmission of its light.[24] But Peters found the distance of this brilliant star to be much greater, since he gives only 0″·103 as the parallax. This result contrasts with another star of the 1st magnitude (α Centauri), and one of the 6th (61 Cygni).

The parallax of the Polar Star has been fixed by Peters at 0″·106, after many comparisons of observations made between the years 1818 and 1838; and this is the more satisfactory, as the same comparisons give the aberration at 20″·455.[25]

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given by Bessel, 0″·3136, 0″·3483, and 0″·3744, this celebrated double star has apparently come gradually nearer to us in light passages amounting respectively to 10, $9\frac{1}{4}$, and $8\frac{7}{10}$ years.

[22] Sir John Herschel, *Outlines*, pp. 545 and 551. Mädler (*Astr.*, s. 425) gives in the case of α Centauri, the parallax 0″·9213 instead of 0″·9128.

[23] Struve, *Stell. compos. Mens. microm.*, pp. clxix.–clxxii. Airy makes the parallax of α Lyræ, which Peters had previously reduced to 0″·1 still lower, indeed too small to be measureable by our present instruments. (*Mem. of the Royal Astr. Soc.*, vol. x. p. 270.)

[24] Struve, on the Micrometrical admeasurements by the Great Refractor at Dorpat, (Oct. 1839,) in Schum., *Astr. Nachr.*, no. 396, s. 178.

[25] Peters, in Struve, *Astr. stell.*, p. 100.

The parallax of Arcturus, according to Peters, is 0″·127. Rümker's earlier observations with the Hamburgh meridian circle had made it considerably larger. The parallax of another star of the 1st magnitude, Capella, is still less, being, according to Peters, 0″·046.

The star No. 1830 in Groombridge's Catalogue, which, according to Argelander, showed the largest proper motion of all the stars that hitherto have been observed in the firmament, has a parallax of 0″·226, according to 48 zenith distances which were taken with much accuracy by Peters during the years 1842 and 1843. Faye had believed it to be five times greater, 1″·08, and therefore greater than the parallax of α Centauri.[26]

| Fixed Star. | Parallax. | Probable Error. | Name of Observer. |
|---|---|---|---|
| α Centauri . . . | 0″·913 | 0″·070 | Henderson and Maclear |
| 61 Cygni . . . | 0″·3744 | 0″·020 | Bessel |
| Sirius . . . . . | 0″·230 | . . | Henderson |
| 1830 Groombridge | 0″·226 | 0″·141 | Peters |
| ι Ursæ Maj. . . | 0″·133 | 0″·106 | Peters |
| Arcturus . . . . | 0″·127 | 0″·073 | Peters |
| α Lyræ . . . . | 0″·207 | 0″·038 | Peters |
| Polaris . . . . | 0″·106 | 0″·012 | Peters |
| Capella . . . . | 0″·046 | 0″·200 | Peters |

It does not in general follow from the results hitherto obtained that the brightest stars are likewise the nearest to us. Although the parallax of α Centauri is the greatest of all at present known, on the other hand, Vega Lyræ, Arcturus, and especially Capella, have parallaxes from three to eight times less than a star of the 6th magnitude in Cygnus. Moreover, the two stars which after 2151 Puppis and ε Indi show the most rapid proper motion, viz. the star just mentioned in the Swan (with an annual motion of 5″·123), and

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[26] Peters, in Struve, *Astr. Stell.*, p. 101.

No. 1830 of Groombridge, which in France is called Argelander's star (with an annual motion of 6″·974), are three and four times more distant from the sun than α Centauri, which has a proper motion of 3″·58. Their volume, mass, intensity of light,[27] proper motion, and distance from our solar system, stand in various complicated relations to each other. Although, therefore, generally speaking, it may be probable that the brightest stars are nearest to us, still there may be certain special very remote small stars, whose photospheres and surfaces, from the nature of their physical constitution, maintain a very intense luminous process. Stars which from their brilliancy we reckon to be of the 1st magnitude, may be further distant from us than others of the 4th, or even of the 6th magnitude. When we pass by degrees from the consideration of the great starry stratum of which our solar system is a part, to the particular subordinate systems of our planetary world, or to the still lower systems of Jupiter's and Saturn's moons, we perceive central bodies surrounded by masses in which the successive order of magnitude and of intensity of the reflected light does not seem to depend on distance. The immediate connexion subsisting between our still imperfect knowledge of parallaxes, and our knowledge of the whole structural configuration of the universe, lends a peculiar charm to those investigations which relate to the distances of the fixed stars.

Human ingenuity has invented for this class of investigations methods totally different from the usual ones, and which, being based on the *velocity of light*, deserve a brief mention in this place. Savary, whose early death proved such a loss to the physical sciences, had pointed out how the aberration of light, in double stars, might be used for determining the parallaxes. If, for instance, the plane of the orbit which the secondary star describes around the central body is not at right angles to the line of vision from the earth to the double star, but coincides nearly with this line of vision itself, then the secondary star in its orbit will likewise appear to describe nearly a straight line, and the points in that portion of its orbit which is turned towards the earth will all be nearer to the observer than the corresponding points of the second half, which is turned away from the earth. Such a division into two halves produces not a real but an apparent unequal velocity, with which the satellite in its orbit recedes from, or approaches, the observer. If the semi-diameter of this orbit were so great that light would require several days or weeks to traverse it, then the time of the half revolution through its more remote side will prove to be longer than the time in the side turned towards the observer. The sum of the two unequal times will always be equal to the *true* periodic time; for the inequalities caused by the *velocity of light* reciprocally destroy each other. From these relations of duration, it is possible, according to Savary's ingenious method of changing days and parts of days into a standard of length, (on the assumption that light traverses 14356 millions of geographical miles in twenty-four hours), to arrive at the absolute magnitude of a semi-diameter of the earth's orbit; and the distance of the central body and its parallax may be then deduced from a simple determination of the angle under which the radius appears to the observer.[28]

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[27] On the proportion of the amount of proper motion to the proximity of the brighter stars. See Struve, *Stell. compos. Mensuræ microm.*, p. clxiv.

In the same way that the determination of the parallaxes instructs us as to the distances of a small number of the fixed stars, and as to the place which is to be assigned to them in the regions of space, so the knowledge of the measure and duration of proper motion, that is to say, of the changes which take place in the positions of self-luminous stars, throws some light on two mutually dependent problems; namely, the motion of the solar system,[29] and the position of the centre of gravity in the heaven of the fixed stars. That which can only be reduced in so very incomplete a manner to numerical relations, must for that very reason be ill calculated to throw any clear light on such causal connexion. Of the two problems just mentioned, the first alone (especially since Argelander's admirable investigation) admits of being solved with a certain degree of satisfactory precision; the latter has been considered with much acuteness by Mädler, but according to the confession of this astronomer himself,[30] his attempted solution is, in consequence of the many mutually compensating forces which enter into it, devoid "of anything like evidence amounting to a complete and scientifically certain proof."

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[28] Savary, in the *Connaissance des Temps pour* 1830, pp. 56–69, and pp. 163–171; and Struve, *ibid.* p. clxiv.

After carefully allowing for all that is due to the precession of the equinoxes, the nutation of the earth's axis, the aberration of light, and the change of parallax caused by the earth's revolution round the sun, the remaining annual motion of the fixed stars comprises at once that which is the consequence of *the translation in space of the whole solar system*, and that also which is the result of the actual proper motion of the fixed stars. In Bradley's masterly labours on nutation, contained in his great treatise of the year 1748, we meet with the first hint of a translation of the solar system, and in a certain sense also with suggestions for the most desirable methods of observing it.[31] "For if our own solar system be conceived to change its place with respect to absolute space, this might, in process of time, occasion an apparent change in the angular distances of the fixed stars; and in such a case, the places of the nearest stars being more affected than of those that are very remote, their relative positions might seem to alter, though the stars themselves were really immoveable. And on the other hand, if our own system be at rest, and any of the stars really in motion, this might likewise vary their apparent positions, and the more so, the nearer they are to us, or the swifter their motions are, or the more proper the direction of the motion is, to be rendered perceptible by us. Since, then, the relative places of the stars may be changed from such a variety of causes, considering that amazing distance at which it is certain some of them are placed, it may require the observations of many ages to determine the laws of the apparent changes even of a single star; much more difficult, therefore, it must be to settle the laws relating to all the most remarkable stars."

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[29] *Cosmos*, vol. i. p. 136.

[30] Mädler, *Astronomie*, s. 414.

[31] Arago, in his *Annuaire pour* 1842, p. 383, was the first to call attention to this remarkable passage of Bradley's. See, in the same *Annuaire*, the section on the translation of the entire solar system, pp. 389–399.

After the time of Bradley, the mere possibility, and the greater or less probability, of the movement of the solar system, were in turn advanced in the writings of Tobias Mayer, Lambert, and Lalande ; but William Herschel had the great merit of being the first to verify the conjecture by actual observations (1783, 1805, and 1806). He found (what has been confirmed, and more precisely determined by many later and more accurate inquiries,) that our solar system moves towards a point near to the constellation of Hercules, in R. A. 260° 44′, and, N. Decl. 26° 16′ (reduced to the year 1800). Argelander, by a comparison of 319 stars, and with a reference to Lundahl's investigations, found it for 1800: R. A. 257° 54′·1, Decl. +28° 49′·2; for 1850, R. A. 258° 23′·5, Decl. +28° 45′·6. Otto Struve (from 392 stars) made it to be for 1800: R. A. 261° 26′·9, Decl. + 37° 35′·5; for 1850, 261° 52′·6, Decl. 37° 33′·0. According to Gauss,[23] the point in question falls within a quadrangle, whose extremes are, R. A. 258° 40′, and Decl. 30° 40′; R. A. 258° 42′, Decl. + 30° 57′; R. A. 259° 13′, Decl. + 31° 9′; R. A. 260° 4′, Decl. + 30° 32′.

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[23] In a letter addressed to me; see Schum. *Astr. Nachr.*, no. 622, s. 348.

It still remained to inquire what the result would be if the observations were directed only to those stars of the southern hemisphere which never appear above the horizon in Europe. To this inquiry Galloway has devoted his especial attention. He has compared the very recent calculations (1830) of Johnson at St. Helena, and of Henderson at the Cape of Good Hope, with the earlier ones of Lacaille and Bradley (1750 and 1757). The result[38] for 1790 was, R. A. 260° 0′, Decl. 34° 23′; therefore for 1800 and 1850, 260° 5′ + 34° 22′ and 260° 33′, + 34° 20′. This agreement with the results obtained from the northern stars is extremely satisfactory.

If then the progressive motion of our solar system may be considered as determined within moderate limits, the question naturally arises: Is the world of the fixed stars composed merely of a number of neighbouring partial systems divided into groups, or must we assume the existence of an universal relation, a rotation of all self-luminous celestial bodies (*suns*) around *one common centre of gravity which is either filled with matter, or void?* We here, however, enter the domain of mere conjecture, to which, indeed, it is not impossible to give a scientific form, but which, owing to the incompleteness of the materials of observation and analogy which are at present before us, can by no means lead to the degree of evidence attained by the other parts of astronomy. The fact that we are ignorant of the proper motion of an infinite number of very small stars from the 10th to the 14th magnitude, which appear to be scattered among the brighter ones, especially in the important part of the starry stratum to which we belong, the

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[38] Galloway, on the *Motion of the Solar System*, in the *Philos. Transact.* 1847, p. 98.

*annuli of the Milky Way*, is extremely prejudicial to the profound mathematical treatment of problems so difficult of solution. The contemplation of our own planetary sphere, whence we ascend, from the small partial systems of the moons of Jupiter, Saturn, and Uranus, to the *higher* and general *solar system*, has naturally led to the belief, that the fixed stars might in a similar manner be divided into several individual groups, and separated by immense intervals of space, which again (in a higher relation of these systems one to another) may be subject to the overwhelming attractive force of a great central body, (one sole sun of the whole universe).[34] The inference here advanced and founded on the analogy of our own solar system, is, however, refuted by the facts hitherto observed, In the *multiple* stars two or more self-luminous stars (suns) revolve, not round one another, but round an external and distant centre of gravity. No doubt something similar takes place in our own planetary system, inasmuch as the planets do not properly move round the centre of the solar body, but around the common centre of gravity of all the masses in the system. But this common centre of gravity falls, according to the relative positions of the great planets Jupiter and Saturn, sometimes within the circumference of the sun's body, but oftener out of it.[35] The centre of gravity, which in the case of the double stars is a void, is accordingly in the solar system at one time void, at another occupied by matter. All that has been advanced with regard to the existence of a dark central body in the centre of gravity of doubie stars, or at least of one originally dark, but faintly illuminated by the borrowed light of the planets which revolve round it, belongs to the ever enlarging realm of mythical hypotheses.

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[34] The value or worthlessness of such views has been discussed by Argelander in his essay, "*Ueber die eigene Bewegung der Sonnensystems, hergeleitet aus der eigenen Bewegung der Sterne*, 1837, s. 39.

[35] See *Cosmos*, vol. i. p. 135. (Bohn's ed.) (Mädler, *Astr.*, p. 400.)

It is a more important consideration, and one more deserving of thorough investigation, that, on the supposition of a revolving movement, not only of the whole of our planetary system which changes its place, but also for the proper motion of the fixed stars at their various distances, *the centre of this revolving motion* must be 90° distant[36] from the point towards which our solar system is moving. In this connexion of ideas the position of stars possessing a *great* or *very small proper motion* becomes of considerable moment. Argelander has examined, with his usual caution and acuteness, the degree of probability with which we may seek for a general centre of attraction for our starry stratum in the constellation of Perseus.[37] Mädler, rejecting the hypothesis of the existence of a central body, preponderating in mass, as the universal centre of gravity, seeks the centre of gravity in the Pleiades, in the very centre of this group, in or near[38] to the bright star $\eta$ Tauri (Alcyone). The present is not the place to discuss the probability or improbability [30] of such an hypothesis. Praise is, however, due to the eminently active director of the Observatory at Dorpat, for having by his diligent labours determined the positions and proper motions of more than 800 stars, and at the same time excited investigations which, if they do not lead to the satisfactory solution of the great problem itself, are nevertheless calculated to throw light on kindred questions of physical astronomy.

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[36] Argelander, *ibid.* p. 42; Mädler, *Centralsonne*, s. 9, and *Astr.*, s. 403.

[37] Argelander, *ibid.* p. 43; and in Schum. *Astr. Nachr.*, no. 566. Guided by no numerical investigations, but following the suggestions of fancy, Kant long ago fixed upon Sirius, and Lambert upon the nebula in the belt of Orion, as the central body of our starry stratum. (Struve, *Astr. Stell.*, p. 17, no. 19.)

[38] Mädler, *Astr.*, s. 380, 400, 407, and 414; in his *Centralsonne*, 1846, pp. 44–47; in *Untersuchungen über die Fixstern-Systeme*, th. ii. s. 183–185. Alcyone is in R. A. 54° 30′, Decl. 23° 36′, for the year 1840. If Alcyone's parallax were really 0″·0065, its distance would be equal to 31½ million semi-diameters of the earth's orbit, and thus it would be 50 times further distant from us than the distance of the double star 61 Cygni, according to Bessel's earliest calculation. The light which comes to the earth from the

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sun in 8′ 18″·2, would in that case take 500 years to pass from Alcyone to the earth. The fancy of the Greeks delighted itself in wild visions of the height of falls. In Hesiod's *Theogonia*, v. 722–725, it is said, speaking of the fall of the Titans into Tartarus: "If a brazen anvil were to fall from heaven nine days and nine nights long, it would reach the earth on the tenth." This descent of the anvil in 777600 seconds of time gives an equivalent in distance of 309424 geographical miles, (allowance being made, according to Galle's calculation, for the considerable diminution in the force of attraction at planetary distances,) therefore 1½ times the distance of the moon from the earth. But, according to the *Iliad*, i. v. 592, Hephaestus fell down to Lemnos in one day, "when but a little breath was still in him." The length of the chain hanging down from Olympus to the earth, by which all the gods were challenged to try and pull down Jupiter (*Iliad*, viii. v. 18), is not given. The image is not intended to convey an idea of the height of heaven, but of Jupiter's strength and omnipotence.

[30] Compare the doubts of Peters, in Schum. *Astr. Nachr.*, 1849, s. 661, and Sir John Herschel, in the *Outl. of Astr.*, p. 589:—"In the present defective state of our knowledge respecting the proper motion of the smaller stars, we cannot but regard all attempts of the kind as to a certain extent premature, though by no means to be discouraged as forerunners of something more decisive."

# VI.

## MULTIPLE OR DOUBLE STARS. — THEIR NUMBERS AND RECIPROCAL DISTANCES.—PERIOD OF REVOLUTION OF TWO SUNS ROUND A COMMON CENTRE OF GRAVITY.

When, in contemplating the systems of the fixed stars, we descend from hypothetical, higher, and more general considerations to those of a special and restricted nature, we enter a domain more clearly determined, and better calculated for direct observation. Among the *multiple stars*, to which belong the *binary* or *double stars*, several self-luminous cosmical bodies (suns) are connected by mutual attraction, which necessarily gives rise to motions in closed curved lines. Before actual observation had established the fact of the revolution of the double stars, such movements in closed curves were only known to exist in our own planetary solar system. On this apparent analogy inferences were hastily drawn, which for a long time gave rise to many errors. As the term "double stars" was indiscriminately applied to every pair of stars, the close proximity of which precluded their separation by the naked eye (as, in the case of Castor, α Lyræ, β Orionis, and α Centauri) this designation naturally comprised two classes of multiple stars: firstly, those which, from their incidental position in reference to the observer, appear in close proximity, though in reality widely distant and belonging to totally different strata; and, secondly, those which, from their actual proximity, are mutually dependent upon each other

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[1] Compare *Cosmos*, vol. i. pp. 136–139. (Struve, *über Doppelsterne nach Dorpater Micrometer-Messungen von* 1824 *bis* 1837, s. 11.)

in mutual attraction and reciprocal action, and thus constitute a particular, isolated, sidereal system. The former have long been called *optically*, the latter *physically*, double stars. By reason of their great distance, and the slowness of their elliptical motion, many of the latter are frequently confounded with the former. As an illustration of this fact, Alcor, (a star which had engaged the attention of many of the Arabian astronomers, because, when the air is very clear, and the organs of vision peculiarly sharp, this small star is visible to the naked eye together with ζ in the tail of Ursa Major, forms, in the fullest sense of the term, one of these *optical* combinations, without any closer physical connexion. In sections II. and III. I have already treated of the difficulty of separating by the naked eye adjacent stars, with the very unequal intensity of light, of the influence of the higher brilliancy and the *stars' tails*, as well as of the organic defects which produce *indistinct* vision.

Galileo, without making the double stars an especial object of his telescopic observations (to which his low magnifying powers would have proved a serious obstacle), mentions (in a famous passage of the Giornata terza of his Discourses, which has already been pointed out by Arago) the use which astronomers might make of *optically* double stars (quando si trovasse nel telescopio qualche picciolissima stella vicinissima ad alcuna delle maggiori) for determining the *parallax of the fixed stars*.[3] As late as the middle of the

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[2] *Vide supra*. As a remarkable instance of acuteness of vision, we may further mention, that Möstlin, Kepler's teacher, discovered with the naked eye fourteen, and some of the ancients nine, of the stars in the Pleiades. (Mädler, *Untersuch. über die Fixtern-Systeme*, th. ii. s. 36.)

[3] *Vide supra*. Doctor Gregory of Edinburgh also, in 1675, (consequently thirty-three years after Galileo's decease), re-

last century, scarcely twenty double stars were set down in the stellar catalogues, if we exclude all those at a greater distance from each other than 32″; at present—a hundred years later (thanks chiefly to the great labours of Sir William Herschel, Sir John Herschel, and Struve), about 6000 have been discovered in the two hemispheres. To the earliest described double stars[4] belong ζ Ursæ maj. (7th September, 1700, by Gottfried Kirch), α Centauri (1709, by Feuillée), γ Virginis (1718), α Geminorum (1719), 61 Cygni (1753), (which, with the two preceding, was observed by Bradley, both in relation to distance and angle of direction), ρ Ophiuchi, and ζ Cancri. The number of the double stars recorded has gradually increased, from the time of Flamstead, who employed a micrometer, down to the star-catalogue of Tobias Mayer, which appeared in 1756. Two acutely speculative thinkers, endowed with great powers of combination, Lambert (*Photometria*, 1760; *Kosmologische Briefe über die Einrichtung des Weltbaues*, 1761) and John Michell, 1767, though they did not themselves observe double stars were the first to diffuse correct views upon the relations of their attraction in partial *binary systems*. Lambert, like Kepler, hazarded the conjecture that the remote suns (fixed stars) are, like our own sun, surrounded with dark bodies, planets, and comets; but of the fixed stars proximate to each other,[5] he believed, however much on the other hand he may appear inclined to admit the existence of dark central bodies, "that within a not very long period they completed a revolution round their common centre of gravity."

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commended the same parallactic method; see Thomas Birch *Hist. of the Royal Soc.*, vol. iii. 1757, p. 225. Bradley (1748) alludes to this method at the conclusion of his celebrated treatise on Nutation.

[4] Mädler, *Astr.*, s. 477.

[5] Arago, in the *Annuaire pour* 1842, p. 400.

Michell[6] who was not acquainted with the ideas of Kant and Lambert, was the first who applied the calculus of probabilities to small groups of stars, which he did with great ingenuity, especially to multiple stars, both binary and quaternary. He showed that it was 500000 chances to 1 that the collocation of the six principal stars in the Pleiades did not result from accident, but that, on the contrary, they owed their grouping to some internal and reciprocal relation. He was so thoroughly convinced of the existence of luminous stars, revolving round each other, that he ingeniously proposed to employ these partial star-systems to the solution of certain astronomical problems.[7]

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[6] An Inquiry into the probable parallax and magnitude of the fixed stars, from the quantity of light which they afford us, and the particular circumstances of their situation, by the Rev. John Mitchell; in the *Philos. Transact.*, vol. lvii. pp. 234–261.

[7] John Michell, *ibid.*, p. 238. "If it should hereafter be found that any of the stars have others revolving about them (for no satellites by a borrowed light *could possibly be visible*), we should then have the means of discovering . . . . ." Throughout the whole discussion he denies that one of the two revolving stars can be a dark planet shining with a reflected light, because both of them, notwithstanding their distance, are visible to us. Calling the larger of the two the "Central Star," he compares the density of both with the density of our sun, and merely uses the word "satellite" relatively to the idea of revolution, or of reciprocal motion; he speaks of the "greatest apparent elongation of those stars, that revolve about others as satellites." He further says, at pp. 243 and 249: "We may conclude with the highest probability (the odds against the contrary opinion being many million millions to one) that stars form a kind of system by mutual gravitation. It is highly probable in particular, and next to a certainty in general, that such double stars as appear to consist of two or more stars placed near together are under the influence of some general law, such perhaps as gravity. . . . ." (Consult also Arago, in the

Christian Mayer, the Manheim astronomer, has the great merit of having first (1778) made the fixed stars a special object of research, by the sure method of actual observations. The unfortunate choice of the term *satellites of the fixed stars*, and the relations which he supposed to exist among the stars between 2° 30′ and 2° 55′ distant from Arcturus, exposed him to bitter attacks from his contemporaries, and among these to the censure of the eminent mathematician, Nicolaus Fuss. That dark planetary bodies should become visible by reflected light, at such an immense distance, was certainly improbable. No value was set upon the results of his carefully conducted observations, because his theory of the phenomena was rejected; and yet Christian Mayer, in his rejoinder to the attack of Father Maximilian Hell, Director of the Imperial Observatory at Vienna, expressly asserts "that the smaller stars, which are so near the larger, are either illuminated, naturally dark planets, or that both of these cosmical bodies—the principal star and its companion—are self-luminous suns revolving round each other." The

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*Annuaire pour* 1834, p. 308. and *Ann.* 1842, p. 400.) No great reliance can be placed on the individual numerical results of the calculus of probabilities given by Michell: as the hypotheses that there are 230 stars in the heavens which, in intensity of light, are equal to β Capricorni, and 1500 equal to the six greater stars of the Pleiades, are manifestly incorrect. The ingenious cosmological treatise of John Michell ends with a very bold attempt to explain the scintillation of the fixed stars by a kind of "pulsation in material effluxes of light"—an elucidation not more happy than that which Simon Marius, one of the discoverers of Jupiter's satellites (see *Cosmos*, vol. ii. p. 404.) has given at the end of his *Mundus Jovialis* (1614) But Michell has the merit of having called attention to the fact (p. 263) that the scintillation of stars is always accompanied by a change of colour. "Besides their brightness there is in the scintillation of the fixed stars a change of colour." (*Vide supra.*)

importance of Christian Mayer's labours has, long after his death, been thankfully and publicly acknowledged by Struve and Mädler. In his two treatises, *Vertheidigung neuer Beobachtungen von Fixstern-trabanten* (1778), and *Dissertatio de novis in Cœlo sidereo Phænomenis* (1779), eighty double stars are described as observed by him, of which sixty-seven are less than 32″ distant from each other. Most of these were first discovered by Christian Mayer himself, by means of the excellent eight-feet telescope of the Manheim Mural Quadrant; "many even now constitute very difficult objects of observation, which none but very powerful instruments are capable of representing, such as ϱ and 71 Herculis, ε Lyræ, and ω Piscium." Mayer, it is true, (as was the practice long after his time,) only measured distances in right ascension and declination by meridian instruments, and pointed out, from his own observations, as well as from those of earlier astronomers, changes of position; but from the numerical value of these he omitted to deduct what (in particular cases) was due to the proper motion of the stars.[8]

These feeble, but praiseworthy beginnings were followed by Sir William Herschel's colossal work on the multiple stars, which comprises a period of more than twenty-five years. For although Herschel's first catalogue of double stars was published four years after Christian Mayer's treatise on the same subject, yet the observations of the former go back as far as 1779—indeed, even to 1776, if we take into consideration the investigations on the trapezium in the great nebula of Orion. Almost all we at present know of the manifold formation of the double stars has its origin in Sir William Herschel's work. In the catalogues of 1782,

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[8] Struve, in the *Recueil des Actes de la Séance publique de l'Acad. Imp. des Sciences de St. Pétersbourg, le* 29 *Déc* 1832, pp. 48–50. Mädler, *Astr.*, s. 478.

1783, and 1804, he has not only set down and determined the position and distance of 846 double stars,[*] for the most part first discovered by himself, but, what is far more important than any augmentation of number, he applied his sagacity and power of observation to all those points which have any bearing on their orbits, their conjectured periodic times, their brightness, contrasts of colours, and classification according to the amount of their mutual distances. Full of imagination, yet always proceeding with great caution, it was not till the year 1794, while distinguishing between optically and physically double stars, that he threw out his preliminary suggestions as to the nature of the relation of the larger star to its smaller companion. Nine years afterwards, he first explained his views of the whole system of these phenomena, in the 93rd volume of the *Philosophical Transactions*. The idea of partial star-systems, in which several suns revolve round a common centre of gravity, was then firmly established. The stupendous influence of attractive forces, which in our solar system extends to Neptune, a distance 30 times that of the earth (or 2488 millions of geographical miles) and which compelled the great comet of 1680 to return in its orbit, at the distance of 28 of Neptune's semi-diameters (853 mean distances of the earth, or 70800 millions of geographical miles), is also manifested in the motion of the double star 61 Cygni, which, with a parallax of 0″·3744, is distant from the sun 18240 semi-diameters of Neptune's orbit (*i. e.* 550900 earth's mean distances, or 45576000 millions of geographical miles).

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[*] *Philos. Transact. for the year* 1782, pp. 40–126; for 1783. pp. 112–124; for 1804, p. 87. Regarding the observations on which Sir William Herschel founded his views respecting the 846 double stars, see Mädler, in Schumacher's *Jahrbuch für* 1839, s. 59, and his *Untersuchungen über die Fixstern-Systeme*, th. i. 1847, s. 7.

But although Sir William Herschel so clearly discerned the causes and general connexion of the phenomena, still, in the first few years of the nineteenth century, the angles of position derived from his own observations, owing to a want of due care in the use of the earlier catalogues, were confined to epochs too near together to admit of perfect certainty in determining the several numerical relations of the periodic times, or the elements of their orbits. Sir John Herschel himself alludes to the doubts regarding the accuracy of the assigned periods of revolution of α Geminorum (334 years instead of 520, according to Mädler),[10] of γ Virginis (708 instead of 169), and of γ Leonis (1424 of Struve's great catalogue), a splendid golden and reddish-green double star (1200 years).

After William Herschel, the elder Struve (from 1813 to 1842), and Sir John Herschel (from 1819 to 1838), availing themselves of the great improvements in astronomical instruments, and especially in micrometrical applications, have, with praiseworthy diligence, laid the proper and special foundation of this important branch of astronomy. In 1820, Struve published his first Dorpat Table of double stars, 796 in number. This was followed in 1824 by a second, containing 3112 double stars, down to the 9th magnitude, in distances under 32″, of which only about one-sixth had been before observed. To accomplish this work, nearly 120000 fixed stars were examined by means of the great Fraunhofer refractor. Struve's third Table of multiple stars appeared in the year 1837, and forms the important work *Stellarum compositarum Mensuræ micrometricæ*.[11] It contains

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[10] Mädler, *ibid.*, th. i. s. 255. For Castor we have two old observations of Bradley, 1719 and 1759 (the former taken in conjunction with Pond, the latter with Maskelyne), and two of the elder Herschel, taken in the years 1779 and 1803. For the period of revolution of γ Virginis, see Mädler, *Fixstern-Syst.*, th. ii. s. 234–40, 1848.

[11] Struve, *Mensuræ microm.*, pp. 40 and 234–248. On the

2787 double stars, several imperfectly observed objects being carefully excluded.

Sir John Herschel's unwearied diligence, during his four years' residence in Feldhausen, at the Cape of Good Hope, which, by contributing to an accurate topographical knowledge of the southern hemisphere, constitutes an epoch in astronomy,[12] has been the means of enriching this number by the addition of more than 2100 double stars (which, with few exceptions, had never before been observed). All these African observations were taken by a twenty-feet reflecting telescope; they were reduced for the year 1830, and are included in the six catalogues which contain 3346 double stars, and were transmitted by Sir John Herschel to the Astronomical Society for the 6th and 9th parts of their valuable *Memoirs*.[13] In these European catalogues are laid down the 380 double stars which the above celebrated astronomer had observed in 1825, conjointly with Sir James South.

We trace in this historical sketch the gradual advance made by the science of astronomy towards a thorough knowledge of *partial*, and especially of *binary systems*. The number of double stars (those both optically and physically double) may at present be estimated with some certainty at about 6000, if we include in our calculation those observed by Bessel with the excellent Fraunhofer heliometer, by Argelander[14]

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whole 2641 + 146, *i. e.* 2787 double stars have been observed. (Mädler, in Schum. *Jahrb.*, 1839, s. 64.)

[12] Sir John Herschel, *Astron. Observ. at the Cape of Good Hope*, pp. 165–303.

[13] *Ibid.*, pp. 167 and 242.

[14] Argelander, in order carefully to investigate their proper motion, examined a great number of fixed stars. See his essay, entitled "*DLX Stellarum fixarum positiones mediæ, ineunte anno* 1830, *ex observ. Aboæ habitis* (*Helsingforsiæ*, 1825)." Mädler (*Astr.*, s. 625) estimates the number of multiple stars in the northern hemisphere, discovered at Pulkowa since 1837, at not less than 600.

at Abo (1827–1835), by Encke and Galle, at Berlin (1836 and 1839), by Preuss and Otto Struve, in Pulkowa (since the catalogue of 1837), by Mädler, in Dorpat, and by Mitchell, in Cincinnati (Ohio) with a seventeen-feet Munich refractor. How many of these 6000 stars, which appear to the naked eye as if close together, may stand in an *immediate relation of attraction* to each other, forming systems of their own, and revolving in closed orbits—or, in other words, how many are so-called *physical* (*revolving*) double stars—is an important problem, and difficult of solution. More revolving companions are gradually but constantly being discovered. Extreme slowness of motion, or the direction of the plane of the orbit as presented to the eye, being such as to render the position of the revolving star unfavourable for observation, may long cause us to class *physically* double stars among those which are only *optically* so; that is, stars of which the proximity is merely apparent. But a distinctly-ascertained appreciable motion is not the only criterion. The perfectly uniform motion in the realms of space, (*i.e.* a common progressive movement, like that of our solar system, including the earth and moon, Jupiter, Saturn, Uranus, and Neptune, with their satellites,) which in the case of a considerable number of multiple stars has been proved by Argelander and Bessel, bears evidence that the principal stars and their companions stand in undoubted relation to each other in separate partial systems. Mädler has made the interesting remark, that whereas previous to 1836, among 2640 double stars that had been catalogued, there were only 58 in which a difference of position had been observed *with certainty*, and 105 in which it might be regarded as more or less *probable;* at present, the proportion of *physically* double stars to *optically* double stars has changed so greatly in favour of the former, that among the 6000 double stars, according to a table published in 1849, 650 are known in which a change of relative position can be incontestably proved.[15] The earliest comparison gave one-sixteenth, the most recent gives one-ninth, as the proportion of the cosmical bodies which, by an observed motion both of the primary star and the companion, are manifestly proved to be physically double stars.

Very little has as yet been numerically determined regarding the relative distribution of the binary star-systems throughout space, not only in the celestial regions, but even on the *apparent vault of heaven*. In the northern hemisphere, the double stars most frequently occur in the direction of certain constellations (Andromeda, Bootes, the Great Bear, the Lynx, and Orion). For the southern hemisphere Sir John Herschel has obtained the unexpected result "that in the extra-tropical regions of this hemisphere the number of multiple stars is far smaller than that in the corresponding portion of the northern." And yet these beautiful southern regions have been explored under the most favourable circumstances, by one of the most experienced of observers, with a brilliant twenty-feet reflecting telescope which separated stars of the 8th magnitude, at distances even of three-quarters of a second.[16]

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[15] The number of fixed stars in which *proper motion* has been undoubtedly discovered (though it may be conjectured in the case of all) is slightly greater than the number of double stars in which *change of position* has been observed. (Mädler, *Astr.*, s. 394, 490, and 520–540.) Results obtained by the application of the Calculus of Probabilities, according as the several reciprocal distances of the double stars are between 0″ and 1″, 2″ and 8″, or 16″ and 32″, are given by Struve, in his *Mens microm.*, p. xciv. Distances less than 0″·8 have been taken, and experiments with very complicated systems have confirmed the astronomer in the hope that these estimates are mostly correct within 0″·1. (Struve, *über Doppelsterne nach Dorpater Beob.*, s. 29.)

[16] Sir John Herschel, *Observations at the Cape*, p. 166.

The frequent occurrence of contrasted colours constitutes an extremely remarkable peculiarity of multiple stars. Struve, in his great work[17] published in 1837, gave the following results with regard to the colours presented by six hundred of the brighter double stars. In 375 of these, the colour of both principal star and companion was *the same and equally intense.* In 101, a mere difference of intensity could be discerned. The stars with perfectly different colours were 120 in number, or one-fifth of the whole; and in the remaining four-fifths the principal and companion stars were uniform in colour. In nearly *one-half* of these six hundred, the principal star and its companion were white. Among those of different colours, combinations of yellow with blue (as in ι Cancri), and of orange with green, (as in the ternary star γ Andromedæ,)[18] are of frequent occurrence.

Arago was the first to call attention to the fact that the diversity of colour in the binary systems principally, or at least in very many cases, has reference to the *complementary* colours—the subjective colours, which when united form white.[19] It is a well known optical phenomenon that a faint white light appears green when a strong red light is brought near it; and that a white light becomes blue when the stronger surrounding light is yellowish. Arago, however, with his usual caution, has reminded us of the fact that even though the green or blue tint of the companion star is sometimes the result of contrast, still on the whole it is impossible to deny the actual existence of green or blue stars.[20] There are

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[17] Struve, *Mensuræ microm.*, pp. lxxvii to lxxxiv.

[18] Sir John Herschel, *Outlines of Astr.*, p. 579.

[19] Two glasses, which exhibit complementary colours, when placed one upon the other, are used to exhibit *white* images of the sun. During my long residence at the Observatory at Paris, my friend very successfully availed himself of this contrivance,—instead of using shade glasses to observe the sun's disc. The colours to be chosen are red and green, yellow and blue, or green and violet. "Lorsqu'une lumière forte se trouve auprès d'une lumière faible, la dernière prend la teinte complémentaire de la prèmiere. C'est là le *contraste;* mais comme le rouge n'est presque jamais pur, on peut tout aussi bien dire que le rouge est *complémentaire* du bleu. Les couleurs voisines du spectre solaire se substituent." "When a strong light is brought into contact with a feeble one, the latter assumes the *complementary* colour of the for-

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mer. This is the effect of *contrast;* but as red is scarcely ever pure, it may as correctly be said that red is the complementary of blue: the colours nearest to the solar spectrum reciprocally change." (Arago, *MS. of* 1847.)

[20] Arago, in the *Connaisance des Temps pour l'an* 1828, pp. 299–300; and in the *Annuaire pour* 1834, pp. 246–250; *pour* 1842, pp. 347–350: "Les exceptions que je cite, prouvent que j'avais bien raison en 1825 de n'introduire la notion physique du *contraste* dans la question des étoiles doubles qu'avec la plus grande réserve. Le bleu est la couleur réelle de certaines étoiles. Il résulte des observations recueillies jusqu'ici que le firmament est non seulement parsemé de soleils *rouges* et *jaunes*, comme le savaient les anciens, mais encore de soleils *bleus* et *verts*. C'est au tems et à des observations futures à nous apprendre si les étoiles vertes et bleues ne sont pas des soleils déjà en voie de décroissance; si les différentes nuances de ces astres n'indiquent pas que la combustion s'y opère à différens degrés; si la teinte, avec excès de rayons les plus réfrangibles, que présente souvent la petite étoile, ne tiendrait pas à la force absorbante d'une atmosphère que développerait l'action de l'étoile, ordinairement beaucoup plus brillante, qu'elle accompagne." "The exceptions I have named proved that in 1825 I was quite right in the cautious reservations with which I introduced the physical notion of *contrast* in connexion with double stars. Blue is the real colour of certain stars. The result of the observations hitherto made proves that the firmament is studded not only with *red* and *yellow* suns, (as was known long ago to the ancients,) but also with *blue* and *green* suns. Time and future observations must determine whether red and blue stars are not suns, the brightness of which is already on the wane; whether the varied appearances of these orbs do not indicate the degree of com-

instances in which a brilliant white star (1527 Leonis, 1768 Can. ven.) is accompanied by a small blue star; others, where in a double star (δ Serp.) both the principal and its companion are blue.[21] In order to determine whether the contrast of colours is merely subjective, he proposes (when the distance allows) to cover the principal star in the telescope by a thread or diaphragm. Commonly it is only the smaller star that is blue: this, however, is not the case in the double star 23 Orionis (696 in Struve's Catalogue, p. lxxx.); where the principal star is bluish, and the companion pure white. If in the multiple stars the differently coloured suns are frequently surrounded by planets invisible to us, the latter, being differently illuminated, must have their *white*, *blue*, *red*, and *green* days.[22]

As the *periodical variability*[23] of the stars is, as we have already pointed out, by no means necessarily connected with their red or reddish colour, so also colouring in general, or a contrasting difference of the tones of colour be-

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bustion at work within them; whether the colour and the excess of the most refrangible rays often presented by the smaller of two stars be not owing to the absorbing force of an atmosphere developed by the action of the accompanying star, which is generally much the more brilliant of the two." (Arago in the *Annuaire pour* 1834, pp. 295–301.)

[21] Struve, *Ueber Doppelsterne nach Dorpater Beobachtungen*, 1837, s. 33–36, and *Mensuræ microm.* p. lxxxiii., enumerates sixty-three double stars, in which both the principal and companion are blue or bluish, and in which therefore the colours cannot be the effect of contrast. When we are forced to compare together the colours of double stars, as reported by several astronomers, it is particularly striking to observe how frequently the companion of a red or orange-coloured star is reported by some observers as blue, and by others as green.

[22] Arago, *Annuaire pour* 1834, p. 302.

[23] *Vide supra*, pp. 175–183.

tween the principal star and its companion is far from being peculiar to the *multiple* stars. Circumstances which we find to be frequent, are not on that account necessary conditions of the phenomena; whether relating to a periodical change of light, or to the revolution in partial systems round a common centre of gravity. A careful examination of the bright double stars (and colour can be determined even in those of the 9th magnitude) teaches that, besides white, all the colours of the solar spectrum are to be found in the double stars, but that the principal star, whenever it is not white, approximates in general to the red extreme (that of the least refrangible rays), but the companion to the violet extreme (the limit of the most refrangible rays). The reddish stars are twice as frequent as the blue and bluish; the white are about 2½ times as numerous as the red and reddish. It is moreover remarkable that a great difference of colour is usually associated with a corresponding difference in brightness. In two cases—in ζ Bootis, and γ Leonis—which, from their great brightness can easily be measured by powerful telescopes, even in the day-time, the former consists of two white stars of the 3rd and 4th magnitudes, and the latter of a principal star of the 2nd, and of a companion of the 3·5th, magnitude. This is usually called the brightest double star of the northern hemisphere, whereas α Centauri[24] and α Crucis, in the southern hemisphere, sur-pass all the other double stars in brilliancy. As in ζ Bootis, so also in α Centauri and γ Leonis, we observe the rare combination of two great stars with only a slightly different intensity of light.

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[24] "This superb double star (α Cent.) is beyond all comparison the most striking object of the kind in the heavens, and consists of two individuals, both of a high ruddy or orange colour, though that of the smaller is of a somewhat more sombre and brownish cast." (Sir John Herschel, *Observations at the Cape of Good Hope*, p. 300.) And, according to the important observations taken by Captain Jacob, of the Bombay Engineers, between the years 1846 and 1848, the principal star is estimated of the 1st magnitude, and the satellite from the 2·5th to the 3rd magnitude. (*Transact. of the Royal Soc. of Edinb.*, vol. xvi. 1849, p. 451.)

No unanimity of opinion yet prevails respecting the variable brightness in multiple stars, and especially in that of companions. We have already[25] several times made mention of the somewhat irregular variability of lustre in the orange-coloured principal star in α Herculis. Moreover, the fluctuation in the brightness of the nearly equal yellowish stars (of the 3rd magnitude) constituting the double star γ Virginis and Anon. 2718, observed by Struve, (1831–1833,) probably indicates a very slow rotation of both suns upon their axes.[26] Whether any actual *change of colour* has ever taken place in double stars (as, for instance, in γ Leonis and γ Delphini); whether their white light becomes coloured, and on the other hand, whether the coloured light of the isolated Sirius has become white, still remain undecided questions.[27] Where the disputed differences refer only to faint tones of colour, we should take into consideration the power of vision of the observer, and if refractors have not been employed, the frequently reddening influence of the metallic speculum.

Among the multiple systems we may cite as ternaries, ξ Libræ, ζ Cancri, 12 Lyncis, 11 Monoc.); as quaternaries 102 and 2681 of Struve's Catalogue, α Andromedæ, ε Lyræ: in θ Orionis, the famous trapezium of the greater nebula of Orion, we have a combination of six,—probably a system subject to peculiar physical attraction, since the five smaller stars (6·3m.; 7m.; 8m.; 11·3m.; and 12m.) follow the proper motion of the principal star 4·7m. No change in their relative positions has yet been observed.[28] In the ternary combinations of ξ Libræ and ζ Cancri, the periodical movement of the two companions has been recognized with great certainty. The latter system consists of three stars of the 3rd magnitude, differing very little in brightness, and the nearer companion appears to have a motion ten times more rapid than the remoter one.

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[25] *Cosmos*, vol. iii. p. 224 and note.

[26] Struve, *über Doppelst. nach Dorp. Beob.*, s. 33.

[27] *Ibid.*, s. 36

The number of the double stars, the elements of whose orbits it has been found possible to determine, is at present stated at from fourteen to sixteen.[29] Of these ζ Herculis has twice completed its orbit since the epoch of its first discovery, and during this period has twice (1802 and 1831) presented the phenomenon of the apparent occultation of one fixed star by another. For the earliest calculations of the orbits of double stars, we are indebted to the industry of Savary (ζ Ursæ Maj.), Encke (70 Ophiuchi), and Sir John Herschel. These have been subsequently followed by Bessel, Struve, Mädler, Hind, Smyth, and Captain Jacob. Savary's and Encke's methods require four complete observations, taken at sufficient intervals from each other. The shortest periods of revolution are thirty, forty-two, fifty-eight, and seventy-seven years; consequently, intermediate between the periods of Saturn and Uranus; the longest that have been determined with any degree of certainty exceed five hundred years, that is to say, are nearly equal to three times the period of Le Verrier's Neptune. The eccentricity of the elliptical orbits of the double stars, according to the investigations hitherto made, is extremely considerable; resembling that of comets, increasing from 0·62 (σ Coronæ), up to 0·95 (α Centauri). The least eccentric interior comet—that of Faye—

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[28] Mädler, *Astr.*, s. 517. Sir John Herschel, *Outl.*, p. 568.

[29] Compare Mädler, *Untersuch. über die Fixstern-Systeme*, th. i. s. 225–275; th. ii. s. 235–240; and his *Astr.*, s. 541. Sir John Herschel, *Outl.*, p. 573.

has an eccentricity of 0·55, or less than that of the orbits of the two double stars just mentioned. According to Mädler's and Hind's calculations, $\eta$ Coronæ and Castor exhibit much less eccentricity, which in the former is 0·29, and in the latter 0·22 or 0·24. In these double stars the two suns describe ellipses which come very near to those of two of the smaller principal planets in our solar system, the eccentricity of the orbit of Pallas being 0·24, and that of Juno, 0·25.

If, with Encke, we consider one of the two stars in a binary system, the brighter, to be at rest, and on this supposition refer to it the motion of the companion, then it follows from the observations hitherto made that the companion describes round the principal star a conic section, of which the latter is the focus; namely, an ellipse in which the radius vector of the revolving cosmical body passes over equal superficial areas in equal times. Accurate measurements of the angles of position and of distances, adapted to the determination of orbits, have already shown, in a considerable number of double stars, that the companion revolves round the principal star considered as stationary, impelled by the same gravitating forces which prevail in our own solar system. This firm conviction, which has only been thoroughly attained within the last quarter of a century, marks a great epoch in the history of the development of higher cosmical knowledge. Cosmical bodies, to which long use has still preserved the name of *fixed stars*, although they are neither rivetted to the vault of heaven nor motionless, have been observed to occult each other. The knowledge of the existence of partial systems of independent motion tends the more to enlarge our view, by showing that these movements are themselves subordinate to more general movements animating the regions of space.

## Elements of the Orbits of Double Stars.

| Name. | Semi-Major Axis. | Eccentricity. | Period of Revolution in years. | Calculator. |
|---|---|---|---|---|
| (1) ξ Ursae Maj. | 3″·857 | 0·4164 | 58·262 | Savary 1830 |
| | 3″·278 | 0·3777 | 60·720 | John Herschel Tables of 1849 |
| | 2″·295 | 0·4037 | 61·300 | Mädler 1847 |
| (2) p Ophiuchi ... | 4″·328 | 0·4300 | 73·862 | Encke 1832 |
| (3) ζ Herculis ... | 1″·208 | 0·4320 | 30·22 | Mädler 1847 |
| (4) Castor ......... | 8″·086 | 0·7582 | 252·66 | John Herschel Tables of 1849 |
| | 5″·692 | 0·2194 | 519·77 | Mädler 1847 |
| | 6″·300 | 0·2405 | 632·27 | Hind 1849 |
| (5) γ Virginis ... | 3″·580 | 0·8795 | 182·12 | John Herschel Tables of 1849 |
| | 3″·863 | 0·8806 | 169·44 | Mädler 1847 |
| (6) α Centauri ... | 15″·500 | 0·9500 | 77·00 | Captain Jacob 1848 |

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